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Technology for Commercial Radioactive Waste Management

Volume 3 of 5

May 1979

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U.S. Department of Energy
Assistant Secretary for Energy Technology
Office of Nuclear Waste Management
Washington, D.C. 20545

Report Coordinated By
Battelle, Pacific Northwest Laboratories
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5.0 INTERIM STORAGE ALTERNATIVES

5.0 INTERIM STORAGE ALTERNATIVES

This section describes conceptual facilities for interim storage of various treated transuranic (TRU) and gaseous wastes produced during fuel reprocessing and mixed oxide fuel fabrication. Alternatives for interim storage of spent fuel prior to reprocessing or geologic isolation are also described. The storage concepts are based on available technology. They do not necessarily represent optimum designs, but are representative of what could be achieved with current capabilities. In actual applications it is reasonable to expect that there could be some improvements over these concepts, reflected in lower costs, lower environmental impacts, or both. These conceptual descriptions provide a reasonable basis for cost analysis and for development of estimates of environmental impacts.

Storage alternatives considered in this document have been selected primarily on the basis of available technology as identified in the ERDA report, Alternatives for Managing Wastes from Reactors and Post-fission Operations in the LWR Fuel Cycle.[1] In Section 5.1, storage of high-level liquid waste in large stainless steel tanks is described. This concept has evolved through experience as the preferred method of storing high-level liquid waste produced in commercial reprocessing operations (should extended storage of liquid waste be desired); no other alternative is described. Section 5.2 describes two interim storage concepts for fuel residue (fuel hulls and hardware) waste storage. These concepts include outdoor subsurface storage and indoor vault storage. In Section 5.3, storage concepts for other nonhigh-level TRU waste are described. These include both indoor and outdoor storage facilities for low-level TRU wastes and intermediate-level TRU wastes. Storage facility installations at the reference fuel reprocessing plant (FRP) and the mixed oxide fuel fabrication plant (MOX FFP), as well as storage at an independent site, are considered.

In Section 5.4, two alternatives for storage of solidified high-level waste are described. In one concept the solidified waste containers are stored in a water basin adjacent to an FRP. This concept could be used in the event additional decay storage is required following solidification to reduce the heat generation rate of HLW canisters prior to placement in a geologic repository. A sealed storage cask concept is also described for location at an independent site, and could be used for extended interim storage of solidified high-level waste in the event a geologic repository is not available.

Section 5.5 describes conceptual storage for large quantities of plutonium oxide. This concept could be used in the event spent fuel is reprocessed for recycle of uranium before a determination on the disposition of the plutonium has been made. Two different-sized storage facilities located at the FRP are described, along with a large facility at an independent site.

Section 5.6 describes a concept for storing krypton gas cylinders. The facility is located at an FRP site and provides 50-year storage for recovered ^{85}Kr, after which the residual krypton would be released to the atmosphere.

Section 5.7 describes alternatives for both short-term and extended storage of spent fuel. A water basin storage concept for relatively short-term storage of unpackaged spent fuel is described. A facility for encapsulating or packaging spent fuel assemblies for

extended storage is also described. In addition, four alternative concepts for extended storage of packaged spent assemblies are described. These include a water basin concept, an air cooled vault concept, a dry caisson concept and a surface storage cask concept. Facilities that would be required to locate the storage facility at an independent site separate from the packaging facility are also described.

REFERENCES FOR SECTION 5.0

1. Alternatives for Managing Wastes from Reactors and Post-fission Operations in the LWR Fuel Cycle. ERDA-76-43, Energy Research and Development Administration, Washington, DC, May 1976.

5.1 HIGH LEVEL LIQUID WASTE STORAGE

5.1 HIGH LEVEL LIQUID WASTE STORAGE

The reprocessor of spent, light water reactor (LWR) fuel has the option of converting high-level liquid waste (HLLW) directly into a solid form or of placing the waste into interim liquid storage prior to solidification. Prior to shipment of the solidified waste to a Federal repository, high-level waste must be stored either as a liquid or solid for several years to allow for radioactive decay to reduce its heat generation rate. (According to present regulations, liquid high-level waste can be stored for no longer than five years.)[1] Up to now, the only method studied or applied for maintaining HLLW for these interim periods is storage in large subsurface tanks. Storage of solidified high-level waste is described in Section 5.4. High-level liquid waste storage is discussed here.

5.1.1 High-Level Liquid Storage in Tanks

Conversion of HLLW to a solid form immediately upon discharge from the reprocessing plant has the advantage of eliminating the need for large-scale tank storage facilities and of reducing facility surveillance requirements, since the waste would be in a less mobile form. The major disadvantage of immediate conversion is that the radioactivity level would be at a maximum at this time. The solidification processes would have to be designed for the higher heat and radiation levels. These higher levels would limit the size of solid waste storage containers and might necessitate interim storage of the containers in a water-cooled basin prior to shipment to a Federal repository. If the HLLW is stored in tanks for several years, the heat load is significantly reduced from that at the time of reprocessing, as shown in Figure 5.1.1. The reduced heat load reduces cooling and processing requirements. Determining the economically optimum storage period requires an analysis beyond the scope of this section.

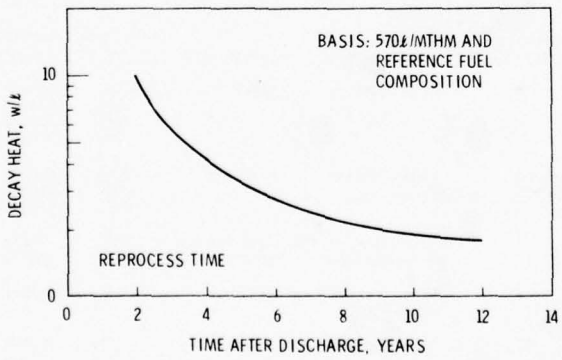


FIGURE 5.1.1. High-level Liquid Waste Tank Storage

The practice of storing HLLW in underground tanks was first adopted at Hanford in 1943 with the initiation of reprocessing of nuclear fuels. Underground tank storage has continued to the present day at Department of Energy (DOE) facilities such as Hanford, Savannah River Plant, and Idaho National Engineering Laboratory. The Nuclear Fuel Services, Inc., West Valley Plant in New York has also used this method since 1968 for storing HLLW from its commercial nuclear fuel reprocessing operation. Tanks have been constructed at the Allied

General Nuclear Services Plant in South Carolina as well, to accommodate interim storage prior to solidification. Underground tank storage is also a common practice at other nuclear fuel reprocessing facilities throughout the world.

Tanks used for the storage of radioactive process waste have ranged in size from 40 to 4900 m^3 (10,000 to 1,300,000 gal) capacity. The tanks are normally located below ground and are built into concrete vaults. The early tanks were of single-wall construction; later tanks have included a secondary containment, either in the form of a second wall or a lining on the wall of the concrete vault. All leaks have been from single-wall tanks, but current designs use double walls and improved quality assurance methods during construction. Agitation has sometimes been used to keep solid particles in suspension and to ensure homogeneity of the solution, thus avoiding hot spots and risks of local corrosion. Systems for condensing vapors, for ventilation, and for monitoring tank level, pressure, specific gravity, and temperature have also been used.

Cases of neutralized HLLW leaking to the ground from carbon steel storage tanks have been reported. The number of leaking tanks has been small, and in each case, the radioactivity associated with the HLLW has been contained in close proximity of the tank. The leaks have resulted in no significant impact on the environment.[2] The multiple containment, improved tank design, and increased quality assurance associated with current tank designs minimize the possibility of leaks. Modern tank designs also include the capability to detect leaks rapidly, provide secondary containment, and transfer the tank's contents to a spare tank should a leak occur.

Table 5.1.1 presents an overview of HLLW tank storage experience, listing characteristic features of some individual installations. A review of the history of this technology, together with a general discussion of its status, is presented in an earlier report.[2]

TABLE 5.1.1. Overview of High-level Liquid Waste Tank Storage

Site	Operational Experience, yr	Waste Source	Waste Type	Tank Size, m^3	Containment Concept	Internal Cooling Coils	Solids Agitation
Hanford (United States)	~31	Pu production	Alkaline	190	Single	No	No
				1890	Single	No	No
				2840	Single	No	No
				3790	Single/Double	No	Yes
Savannah River (United States)	~21	Pu production	Alkaline	2840	Double	Yes	No
				3900	Double	Yes	No
				4920	Single/Double	Some	No
Nuclear Fuel Services (United States)	~9	Power reactor and Pu production	Alkaline and acidic	2840	Double	Yes	Yes
				60	Double	Yes	No
Idaho National Engineering Laboratory (United States)	~20	Pu production and naval fuels	Acidic	1135	Double	Yes	No
Windscale (United Kingdom)	~23	Power reactor	Acidic	70	Double	Yes	No
				150	Triple	Yes	Yes
LaHague & Marcoule (France)	~17	Power reactor and Pu production	Acidic	60	Double	Yes	Yes
				90	Double	Yes	Yes
Eurochemic (Belgium)	~9	Power reactor and Pu production	Acidic	40	Double	Yes	Yes
				210	Double	Yes	Yes
				260	Double	No	---(a)
				500	Double	No	---(a)
Barnwell Nuclear Fuel Plant (United States)	0	Power reactor	Acidic	1140	Double(b)	Yes	Yes

a. Not found in literature.
b. Both containment barriers can be monitored.

Although storage of waste in tanks is considered an interim measure, waste can be stored in this manner indefinitely if surveillance is continued, with transfer to new tanks if necessary. To date, corrosion of stainless steel waste tanks has been negligible. The lifetime of the stainless steel tanks has not yet been determined since no leaks have occurred.

5.1.1.1 Alternatives for High-level Liquid Waste Tank Storage

As noted in Table 5.1.1, HLLW can be stored in either the alkaline or acidic state. The greatest volume of HLLW to date has been stored in the alkaline state; planned commercial nuclear FRPs, however, are expected to store the liquid waste as an acid for the following reasons:

- The addition of large quantities of sodium hydroxide results in increased volumes during both interim tank storage and subsequent handling and storage of the solidified waste.
- Neutralization of commercial high-level wastes produces additional solids (sludges) containing very high heat loads compared to neutralized defense wastes. Storage of sludges at these higher heat levels has not been demonstrated.
- Storage in the acidic state retains maximum flexibility for later waste treatments.
- Processes presently being developed for solidification of commercial HLLW assume acidic waste.

Thus alkaline (or neutralized) waste storage is not considered further in this study.

Figure 5.1.2 graphically presents the options available for selecting a system for interim storage of acidic HLLW. The heavy line represents the HLLW storage system selected for this study. The selected system incorporates established and safe practices for HLLW storage. The reference facility and its operation are modeled after the Allied General Nuclear Services Facility.[3,4] The HLLW is assumed to be stored in underground stainless steel tanks in the acidic state for a period of up to 5 years following discharge from the reprocessing plant.

5.1.1.2 Design Basis for the High-level Liquid Waste Tank Storage Facility

The following assumptions were made in the design of the reference facility:

- The facility will be associated with the operation of a 2000-MTHM FRP. All supporting facilities and services, except for the direct tank farm operation, will be part of the reprocessing plant.
- The tank farm will receive HLLW from the FRP at a rate of 1100 m^3/yr (300,000 gal/yr).
- The HLLW has the characteristics shown in Tables 5.1.2, 5.1.3 and 5.1.4.
- Storage capacity for 5 years production of HLLW will be provided.
- Safety and ease of waste retrieval are primary design considerations.
- The waste will be contained by multiple monitored barriers designed for minimum dependence on people and devices.
- The ability to assess the integrity of each containment barrier at any time will be provided.

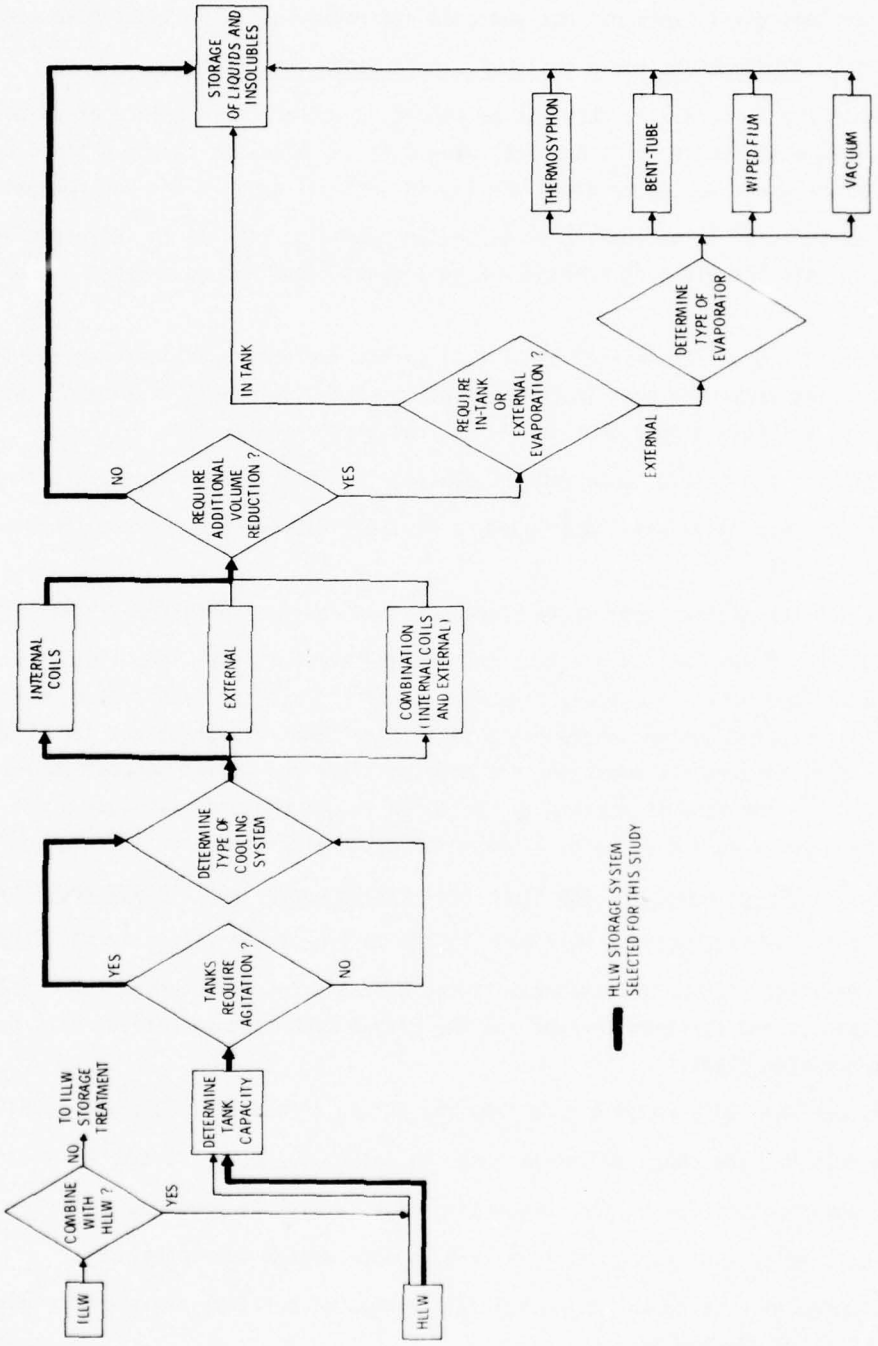


FIGURE 5.1.2. Process Options for Interim Storage of Acidic High-level Liquid Waste

TABLE 5.1.2. Composition of High-level Liquid Waste[a]

Chemicals	g/ℓ
HNO_3	380
H_3PO_4	2.7
$NaNO_3$	0.5
$Fe(NO_3)_3$	8.7
$Cr(NO_3)_3$	1.5
$Ni(NO_3)_2$	0.4
$Gd(NO_3)_3$	34
FP Nitrate[b]	136
Actinide Nitrate[b]	18

a. Basis: mixed oxide fuel; 29,000 MWD/MTHM burnup; 1.5 yr cooling; 570 ℓ/MTHM.
b. For details see Table 4.1.1.

TABLE 5.1.3. Properties of High-level Liquid Waste

Specific volume	570 ℓ/MTHM
Specific gravity	∿1.3
Viscosity	1-2 cp
Specific heat	0.87 cal/g°C
Decay heat	See Figure 5.1.1
HLLW generation rate	3800 ℓ/day

TABLE 5.1.4. Radioactivity Content and Heat Generation Rate in High-level Liquid Waste[a]

Fission Product Content, Ci/MTHM	0 Years After Separation[b]	2 Years After Separation[b]	5 Years After Separation[b]
^{3}H	3.4×10^{1}	3.0×10^{1}	2.6×10^{1}
^{85}Kr	0	0	0
^{129}I	1.8×10^{-4}	1.8×10^{-4}	1.8×10^{-4}
$^{90}Sr + {}^{90}Y$	1.2×10^{5}	1.2×10^{5}	1.1×10^{5}
$^{95}Zr + {}^{95}Nb$	1.1×10^{4}	4.6	3.9×10^{-5}
$^{106}Ru + {}^{106}Rh$	3.8×10^{5}	9.4×10^{4}	1.2×10^{4}
$^{134}Cs + {}^{137}Cs + {}^{137m}Ba$	3.0×10^{5}	2.3×10^{5}	1.8×10^{5}
$^{144}Ce + {}^{144}Pr$	4.8×10^{5}	8.2×10^{4}	5.6×10^{3}
All other FPs	1.0×10^{5}	5.6×10^{4}	2.5×10^{4}
Total FPs	1.4×10^{6}	5.8×10^{5}	3.3×10^{5}
Actinide Content, Ci/MTHM			
^{239}Pu	1.8	1.8	1.8
^{241}Pu	8.7×10^{2}	8.0×10^{2}	6.9×10^{2}
Other Pu	3.1×10^{1}	8.0×10^{1}	8.3×10^{1}
$^{242}Cm + {}^{244}Cm$	1.7×10^{4}	7.1×10^{3}	5.9×10^{3}
All other actinides	1.0×10^{3}	9.9×10^{2}	9.2×10^{2}
Total actinides	1.9×10^{4}	8.9×10^{3}	7.6×10^{3}
Heat Generation Rate W/MTHM	7.1×10^{3}	2.8×10^{3}	1.4×10^{3}

a. Based on waste characterization Table 3.3.29 assuming uranium and plutonium recycle.
b. 1.5 years elapse between reactor discharge and chemical separation, chemical separation assumed to remove 99.5% of U and Pu but no other actinides.

- Critical items, whose continued integrity and operability are essential to ensure containment, will be designed to withstand the stresses imposed under design basis accidents.
- All required functions, such as cooling, ventilation, and power, will be assured by backup systems to maintain acceptable operating conditions at all times.
- Retrieval of the waste from the tanks will be simplified by minimizing the volume of insoluble solids, providing suitable agitation to keep the solids from settling, and avoiding obstructions on the tank bottom which could result in buildup of solids.
- The working volume of each tank will be 1140 m^3 plus a 10% freeboard.
- The capability will be maintained to empty a tank within 3 days.
- Detection systems will be employed that are sensitive to any HLLW leakage from the primary container.
- There will always be one spare tank in the tank farm capable of accommodating the contents of any tank in use.
- The amount of radioactivity in effluents from the tank farm will be "as low as reasonably achievable," and in all cases well within the limits of Federal regulations.[1]
- The tanks will be designed for 100 years of operation.
- The HLLW tank storage facility will be located in the reprocessing plant exclusion area. This arrangement reduces the distance over which the HLLW must be piped.
- The storage facility will be selected to take advantage of natural barriers that would confine or greatly reduce and delay the release of radioactive material to accessible water supplies, in the unlikely event that primary and secondary tank containment barriers fail. Soil properties and area hydrology are also important considerations in evaluating prospective sites. Backfill soils with good retention or ion exchange characteristics must be available in the tank facility area. The site should enable location of the waste tank entirely above the 100-year maximum expected water table elevation.

5.1.1.3 Operation of the High-level Liquid Waste Tank Storage Facility

The primary function of the facility is to receive and store HLLW from the reprocessing of LWR fuels for a period of up to 5 years. Each metric ton of nuclear fuel reprocessed generates about 4200 ℓ (1100 gal) of unconcentrated HLLW. Before transferring the waste to a storage tank, the waste is concentrated to 570 ℓ/MTHM to minimize storage requirements and to recover some of the nitric acid. The degree of volume reduction is determined by two criteria: minimizing precipitated solids and assuring that the radioactive decay heat does not exceed the tank cooling capacity.

Figure 5.1.3 is a schematic drawing of the reference HLLW storage tank. Figure 5.1.4 is a flowsheet for the reference tank storage operation; Table 5.1.5 gives the material balance. Six HLLW tanks are required to provide sufficient storage for 4 years of equilibrium reprocessing plant operation at 2000 MTHM/yr. Each of the six tanks will have the capacity to store HLLW from a year's operation, but with one tank filling, one tank feeding a waste solidification operation and one tank empty (as a spare), the maximum inventory will be 4 years' worth of

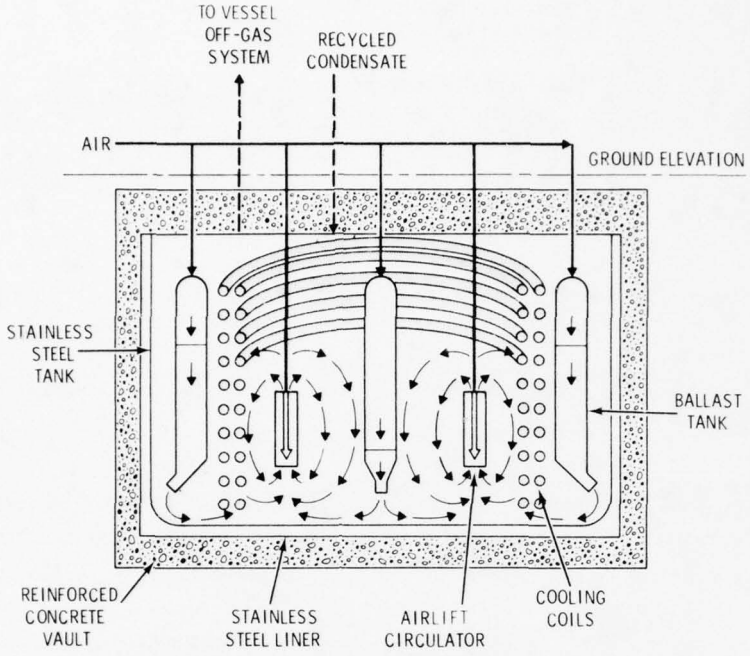


FIGURE 5.1.3. Schematic of a High-level Liquid Waste Storage Tank

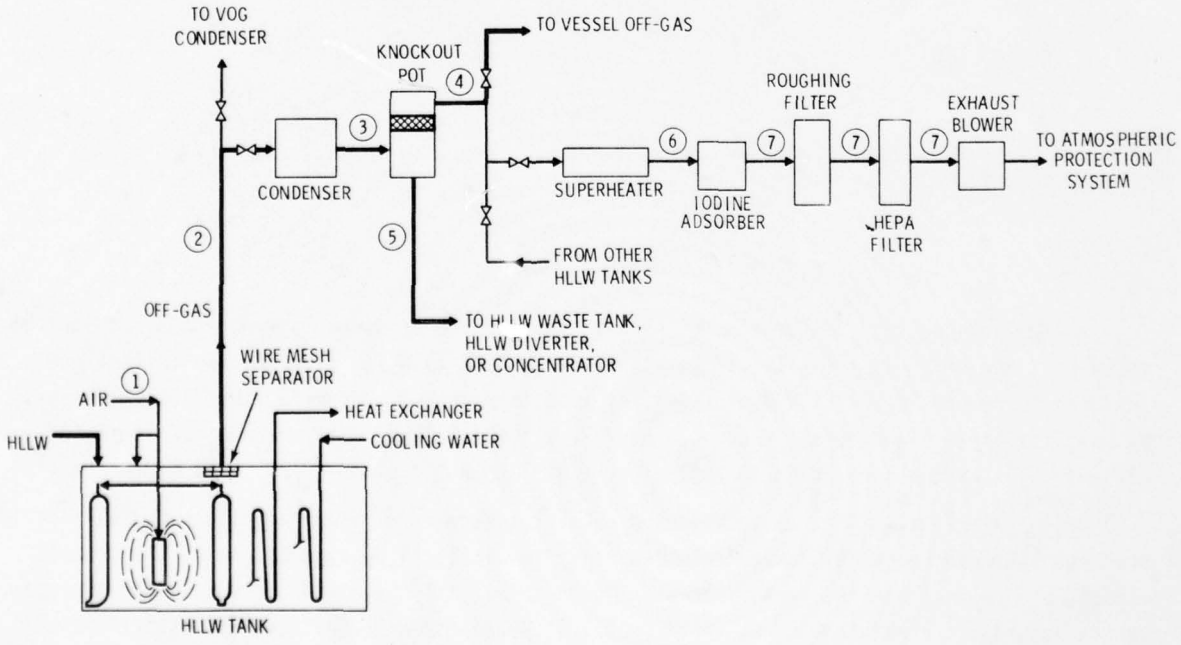


FIGURE 5.1.4. High-level Liquid Waste Tank Storage Operation Flowsheet (Circled numbers refer to stream numbers given in Table 5.1.4.)

TABLE 5.1.5. Material Balance for the High-level Liquid Waste Storage Facility[a]

Stream Numbers	Process Flow Rates, kg/day							Temperature, °C	Density, g/cm^3
	HNO_3	H_2O	N_2	O_2	NO	NO_2	Total Flow		
1	--	1,280	64,000	19,400	--	--	84,680	27	1.18×10^{-3}
2	60	10,230	64,000	19,140	60	820	94,310	60	1.10×10^{-3}
3	60	10,230	64,000	19,140	60	820	94,310	38	2 phases
4	--	3,020	64,000	19,140	60	820	87,040	38	1.14×10^{-3}
5	60	7,210	--	--	--	--	7,270	38	9.9×10^{-1}
6	--	3,020	64,000	19,140	60	820	87,040	125	0.9×10^{-3}
7	--	3,020	64,000	19,140	60	820	87,040	125	0.90×10^{-3}

a. Material balance is based on the equilibrium operation of five HLLW tanks; Tanks 2, 3 and 4 are full; Tanks 1 and 5 are half full. Flow rates are the totals for these five tanks.

liquid waste. Because of the decrease in heat generation of the decaying wastes, tank costs can be reduced by varying the heat removal capacity of the tanks as shown in Table 5.1.6. Aged wastes will be routinely transferred to the lower cooling capacity tanks.

TABLE 5.1.6. Cooling Capacity of High-level Liquid Waste Tanks

Tank Number	Cooling Capacity	
	MW	Btu/hr
1	11	3.9×10^7
2	11	3.9×10^7
3	8	2.7×10^7
4	8	2.7×10^7
5	6	2.0×10^7
6[a]	11	3.9×10^7

a. Spare tank.

Waste Tank Cooling. Internal cooling coil systems are provided to remove the radioactive decay heat and maintain the waste temperatures below 60°C (140°F). The cooling systems are designed to remove 10 W/ℓ (130 Btu/hr-gal) of heat for Tanks 1, 2 and 6; 7 W/ℓ (90 Btu/hr-gal) of heat for Tanks 3 and 4; and 5 W/ℓ (65 Btu/hr-gal) for Tank 5. The overall heat transfer coefficient (U_o) for the tank coils is estimated to be 1.9 to 2.4 W/m^2 °C (40 to 50 Btu/hr-ft^2-°F).[3,5]

Waste Tank Ventilation. A ventilation exhaust system is provided to dilute radiolytically produced hydrogen below its lower explosive limit in air (4.1% by volume), to dilute organic vapors, and to maintain the tank vapor space under a slightly negative pressure. The hydrogen generation rate for acidic HLLW is based on 0.7 standard m^3/MW-hr (7.5 standard ft^3/10^6 Btu) of decay heat.[3] Part or all of the ventilation air may be supplied by the airlift circulator agitation system while the remainder is supplied as a vapor space purge.

Waste Tank Agitation. An agitation system, employing airlift circulators and ballast tanks, is provided to minimize the settling of solids. Without adequate agitation, local "hot" spots can occur at points where the insoluble material in acidic HLLW accumulates and can cause accelerated corrosion of the primary container. The sources of this particulate matter are undissolved solids from the dissolver and precipitates formed during HLLW concentration. Characteristics of the solids are listed in Table 5.1.7.

TABLE 5.1.7. Insoluble Solids in High-level Liquid Waste

	Substance	Quantity	Density
Dissolver solids	Tc, Ru, Pd, Si, Rh, Zr, Mo, Ni, and Fe	150 kg/day (330 lb/day) maximum combined undissolved solids	$\sim$1.8 g/cm^3
Evaporator solids	Zr-Mo-P compounds and others yet to be identified	180 kg/day (395 lb/day) precipitated at 470 ℓ/MTHM	$\sim$1.8 g/cm^3

Waste Tank Acidity Control. The concentration of nitric acid in the HLLW tank is controlled between 1 and 4 M to avoid excessive solids precipitation and to minimize corrosion of the tank. The tank is initially primed about one-third full with dilute nitric acid ($\sim$1.0 M), and HLLW enters the tank at about 5 to 6 M.

The dilute acid used to initially prime the tank evaporates during the fill period, thereby increasing the tank acidity. At the same time, however, nitric acid is being destroyed by radiolysis. A postulated mechanism for the radiolytic destruction is described as follows:

$$3H^+ + 3NO_3^- \rightsquigarrow 3H^+ + 3NO_2^- + \frac{3}{2} O_2$$

$$3HNO_2 \rightsquigarrow NO_3^- + 2NO + H_2O + H^+$$

In this mechanism, NO is removed from the waste by the sparge air supplied to the airlift circulators. The purge air supplied to the tank vapor space does not assist radiolytic destruction of HNO_3. Only sparge air is effective. A mole of HNO_3 is destroyed for every mole of NO produced.

As part of the acidity control system, means are provided for accurately measuring HNO_3 concentration in the waste tank as well as for adding HNO_3 to the tank to compensate for radiolytic destruction. The rate of destruction of HNO_3 is estimated to be 5×10^{-5} g-moles/W-hr (3×10^{-8} lb-moles/Btu).

Waste Tank Off-Gas Decontamination. The off-gas system provides for the decontamination of off-gas from the HLLW tanks. The gas primarily consists of saturated air from the airlift circulators, ballast tanks, and vapor space purge, as well as any hydrogen produced by radiolysis of water. Nitric oxide (NO), nitrogen dioxide (NO_2), iodine and tritium (as tritiated water vapor) are also present.

The waste tank off-gas system is designed to provide flexibility in the handling of the waste tank off-gas flows. Three flow patterns are provided for the treatment of the waste tank off-gas (see Figure 5.1.3). During normal operation the off-gas from a tank is passed through its own condenser and knockout pot (one each per tank) and then routed collectively to the FRP vessel off-gas system. In the event the vessel off-gas system is down, the airflow from the knockout pots is routed through a common superheater, iodine adsorber, roughing filter, and HEPA filter before being discharged to the FRP APS and stack. The third flow pattern provides for direct routing of the vapor loads to the FRP vessel off-gas condenser, bypassing the tank condensers and knockout pots.

5.1.1.4 HLLW Tank Storage Facility Description

The reference HLLW interim storage facility is a subsurface cluster of tanks surrounding an auxiliary equipment building. Figures 5.1.5 and 5.1.6 show a layout of the tank farm, along with the associated reprocessing plant and emergency cooling pond.

General Description. As indicated in Figure 5.1.5, the HLLW tank facility (35) is near the FRP process building (4), the cooling towers (12), the retention basin (34), and the ventilation and blower station (11). The center of the interim storage facility is about 150 m (500 ft) from the main process building. Close proximity assists gravity flow of the HLLW from the concentrator surge tank in the FRP through the diverters and into the storage tanks.

Figure 5.1.7 shows the six HLLW storage tanks encircling the Waste Tank Equipment Building (WTEB). The tanks are stainless steel and are contained in a stainless steel-lined, reinforced concrete vault. The WTEB houses most of the auxiliary equipment, services and controls required for facility operation. The diverter cell, which controls HLLW routing to the tanks, is beneath the heat exchanger gallery in the WTEB. The diverter cell is shown at grade in Figure 5.1.8. Its central location minimizes the distance of gravity flow from the diverter to the storage tanks. This figure also shows the pipe vaults serving the storage tanks.

The large emergency cooling pond, shown in Figure 5.1.6, is located within a separately fenced area, about 300 m (1000 ft) from the FRP plot limits. Placing of the pond at this location obviates undue moisture effects on the FRP plant area from this large body of water. The cooling pond is 490 m (1600 ft) square by 3 m (10 ft) deep, plus 0.6 m (2 ft) of freeboard. A 6-in. impermeable clay layer, covered with 0.3 m (1 ft) of graded aggregate prevents the water from seeping underground. The total capacity of this pond is 7×10^5 m^3 (190 million gal).

The retention basin in Figure 5.1.5, which holds radioactively contaminated cooling water (should this be necessary), is 93 m (300 ft) wide, 118 m (390 ft) long, and 3.7 m (12 ft) deep at the high water line. It is concrete-lined with a 6 in. clay underlayer and has a capacity of 3.7×10^4 m^3 (9.8 million gal). It also has an additional 0.6 m (2 ft) freeboard.

HLLW tanks, piping vaults, diverter cell, emergency cooling water piping, off-gas system waste tank equipment building, utilities pipe vaults, and emergency cooling pond pump house are all designed to Category I[(a)] specifications.

a. Category I structures are designed to withstand design-basis tornadoes, earthquakes, and floods.

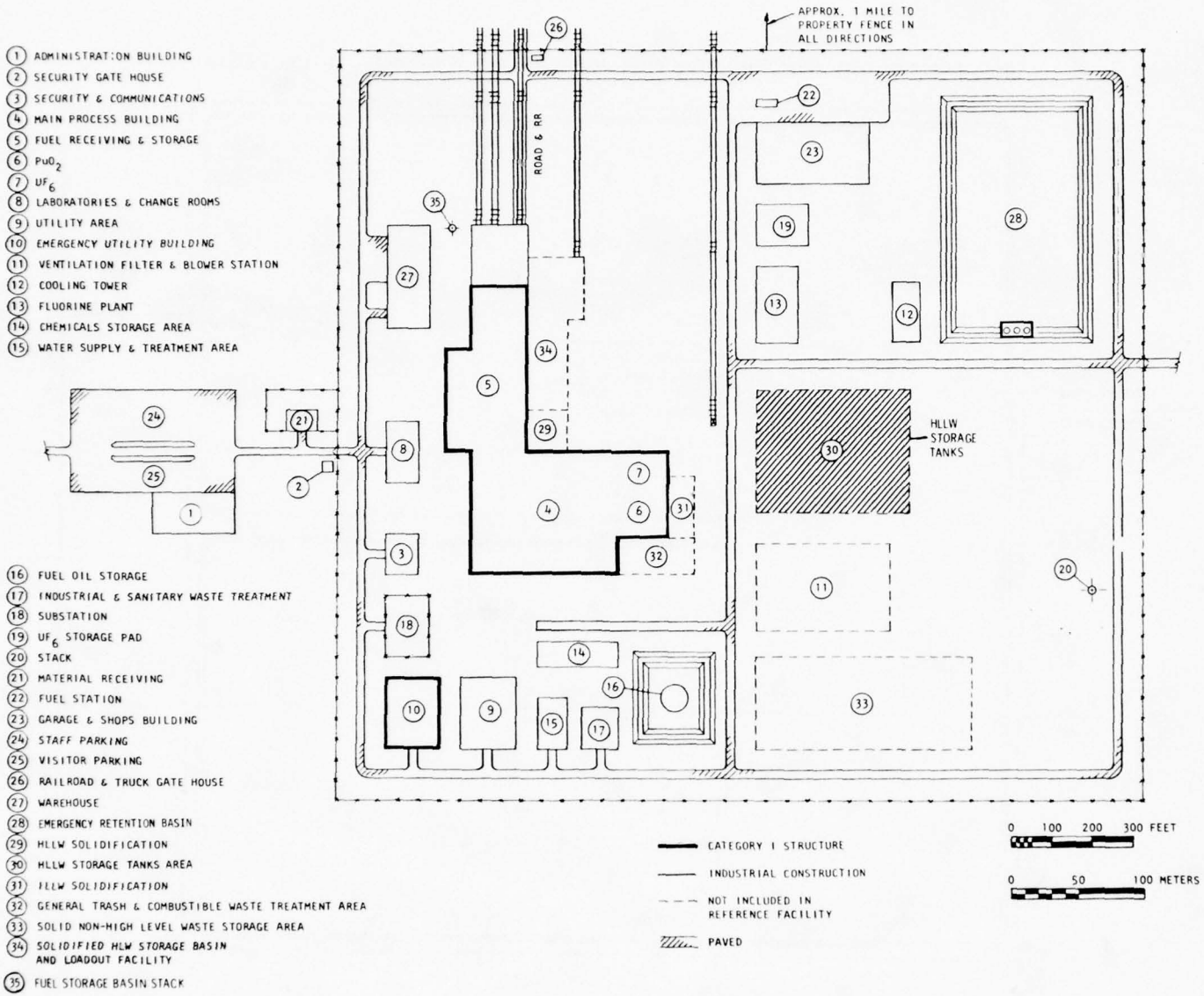


FIGURE 5.1.5. Location of the High-level Liquid Waste Storage Tanks Within the Fuel Reprocessing Plant

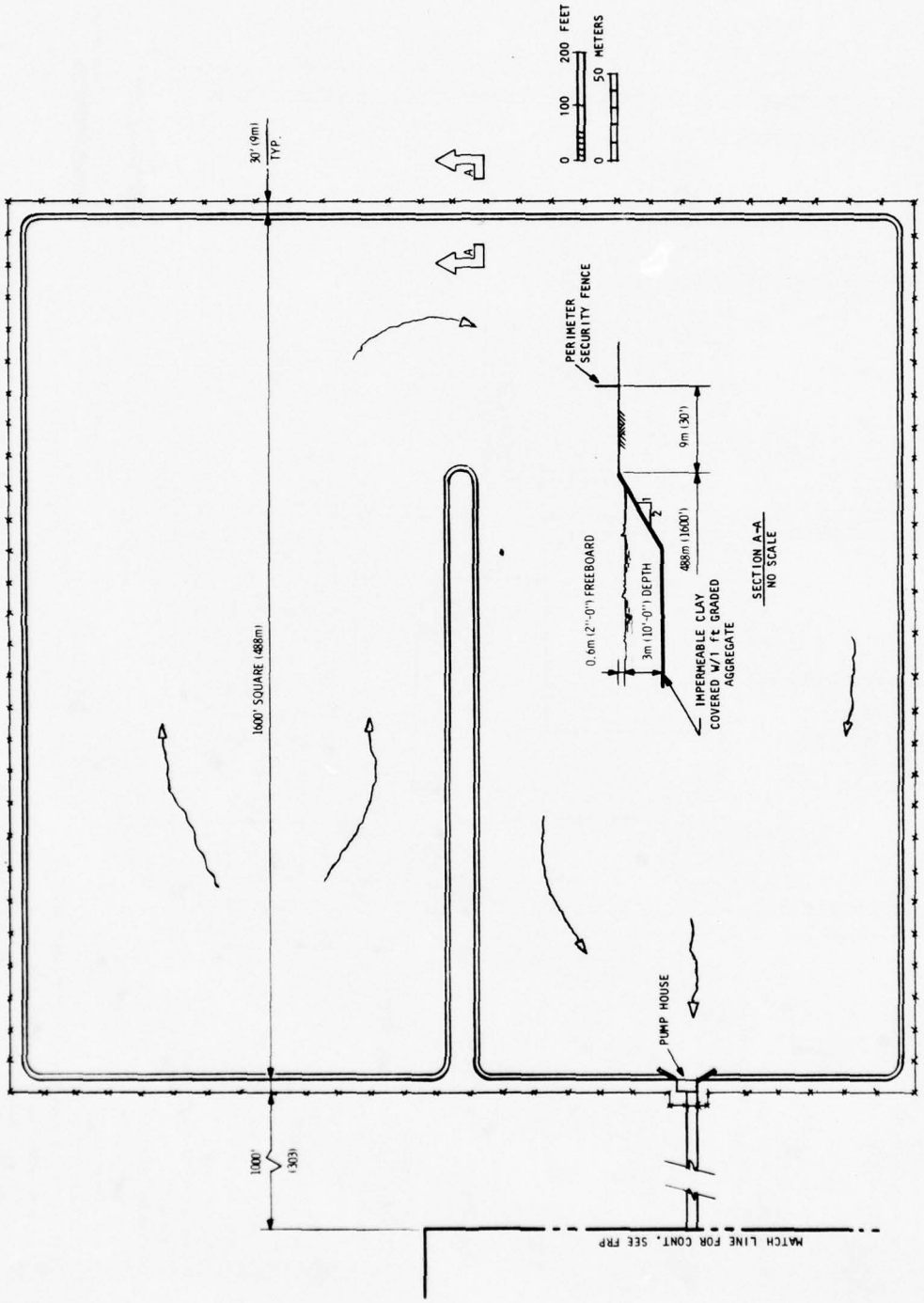


FIGURE 5.1.6. Emergency Cooling Water Pond Adjoining Fuel Reprocessing Plant

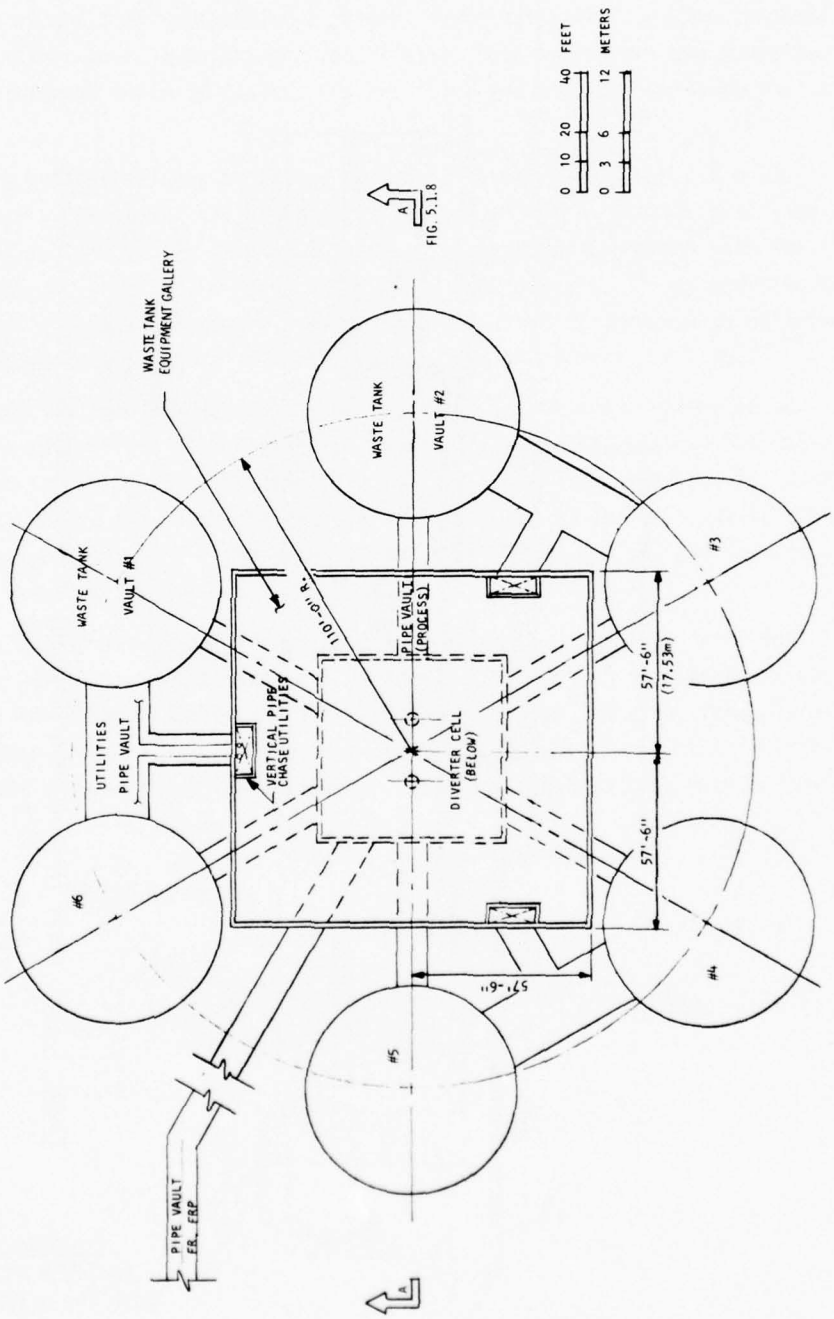


FIGURE 5.1.7. Waste Tank Equipment Building and Storage Tanks, Top View

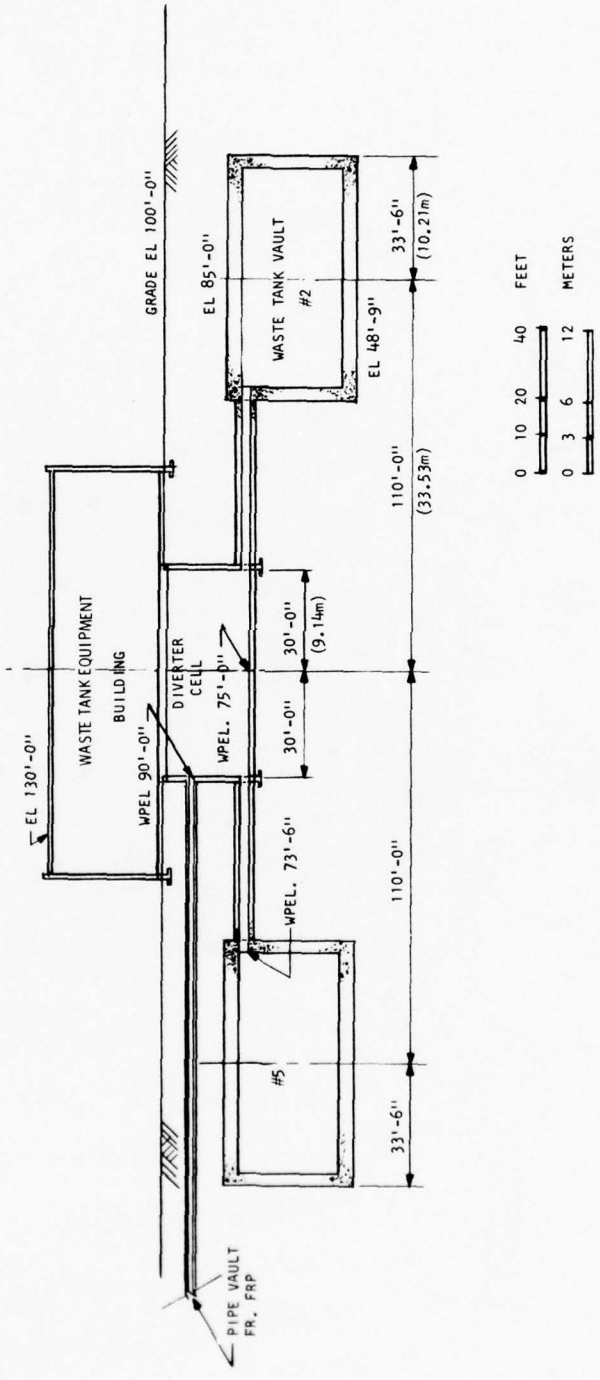


FIGURE 5.1.8. Waste Tank Equipment Building and Associated Facilities, Side View

Storage Tanks. The storage tanks are designed to safely contain acidic HLLW for a minimum lifetime of 100 years. They are 17 m (54 ft) in diameter and 6 m (20 ft) high and have a net tank storage volume of 1140 m^3 (300,000 gal) with 10% freeboard. The double containment used in construction of the tank consists of a primary stainless steel container encased in a stainless steel liner to full height of liquid fill. Both containers are supported by and encased in a reinforced concrete vault. Figures 5.1.9 and 5.1.10 illustrate the tank construction.

The primary container floor is 1.3 cm (0.5 in.) thick. The lower 2.4 m (8 ft) of the walls is also 1.3 cm thick and the upper 3.7 m (12 ft) of the tank walls is 1.1 cm (7/16 in.) thick. The tank top is 0.95 cm (3/8 in.) thick. The expected corrosion rate for the stainless steel tank containing acidic HLLW is $\leq$0.013 mm/yr ($\leq$0.05 mil/yr).[7] In addition to the stresses imposed by natural phenomena, the primary container is designed to withstand the hydrostatic load caused by 1140 m^3 of waste with a specific gravity of 1.35.

The concrete vault that contains the HLLW tank has an inside diameter of 18 m (60 ft) and an inside height of 8 m (26 ft). The vault floor is 1.2 m (4 ft) thick. The walls are 0.9 m (3 ft) thick and support a top 1.5 m (5.5 ft) thick. A stainless steel vault liner, 0.64 cm (1/4 in.) thick, covers the floor and extends 5.5 m (18 ft) up the vault wall. This secondary container is designed to support the primary container and to prevent any leak from the primary container from entering the ground.

Continuous monitoring of the integrity of the primary container is provided. This is accomplished by supporting the primary container off the floor of the secondary container by stainless steel strips and sloping the floor of the secondary container from all directions to a vault sump. Any liquid drains to the sump and is detected by redundant liquid level indicators. Periodic assessment of the secondary container's integrity is provided by collecting

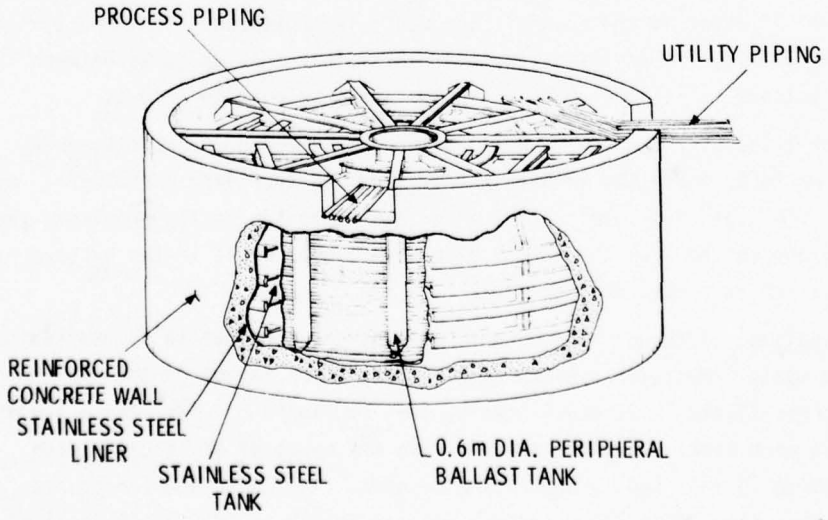


FIGURE 5.1.9. High-level Liquid Waste Storage Tank

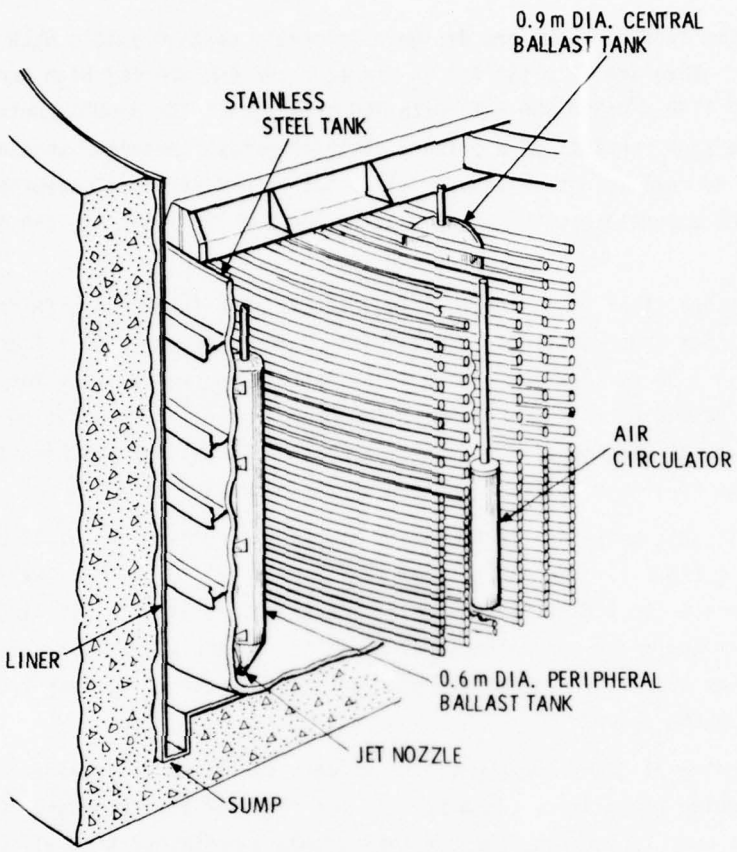


FIGURE 5.1.10. Cross Section of High-level Liquid Waste Tank

channels installed behind all the welds in the wall liner and by a monitoring space under the floor liner. To check the integrity of the vault liner, the channel system is filled with water and the level of water in the channels and vault is monitored. This monitoring system is shown in Figure 5.1.11. In addition, there is sufficient annular space between the primary and secondary containers to allow visual inspection using television cameras.

The HLLW is retrievable, and the tank is designed for eventual decommissioning. Equipment for transferring waste is installed in both the primary and secondary containers. Spare equipment is provided. To avoid possible corrosion and tank decontamination problems, the tank design eliminates obstructions on the tank bottom that could result in the buildup of solids. All tank internals are supported from the tank top.

Waste Tank Cooling. Internal cooling coil systems are provided to remove radioactive decay heat, keeping the waste temperatures below 60°C (140°F). The layout of the cooling coils for the high heat waste tanks (Tanks 1, 2, and 6) can be seen in Figure 5.1.12. There are 48 horizontal coils installed in each tank. They are divided into six banks of eight coils each. Each bank is connected to 15-cm (6 in.) supply and return headers. The coils are constructed of 2-in. schedule 80 stainless steel pipe and represent a total length of 10.9 km (6.8 miles). If one

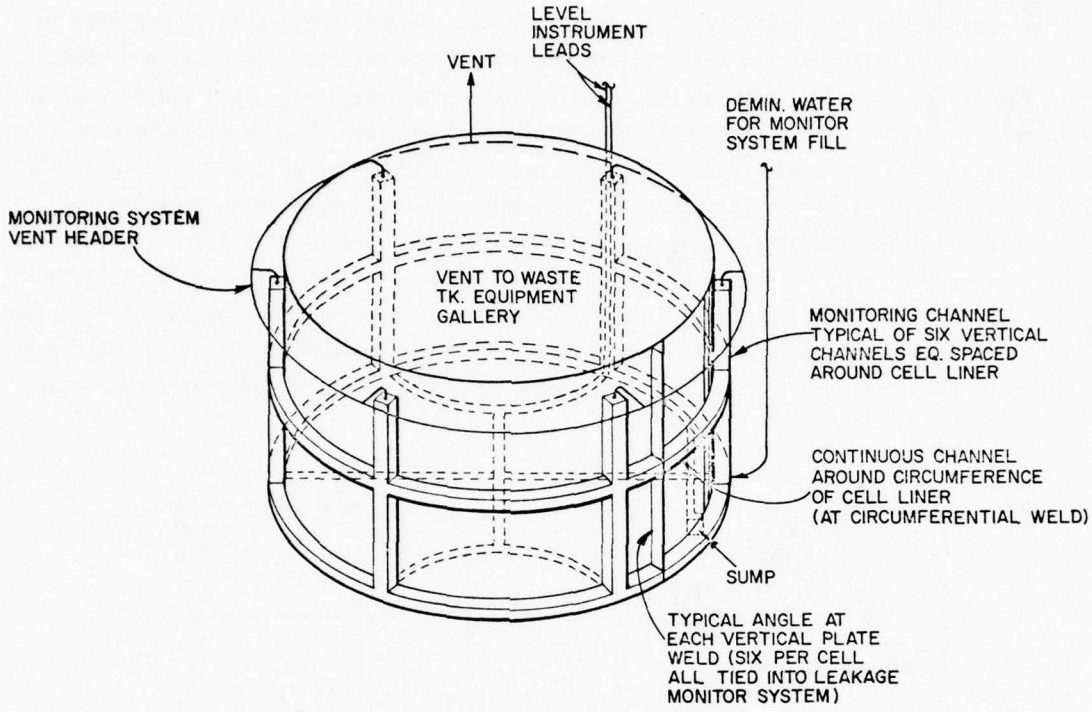


FIGURE 5.1.11. Secondary Container Monitoring System

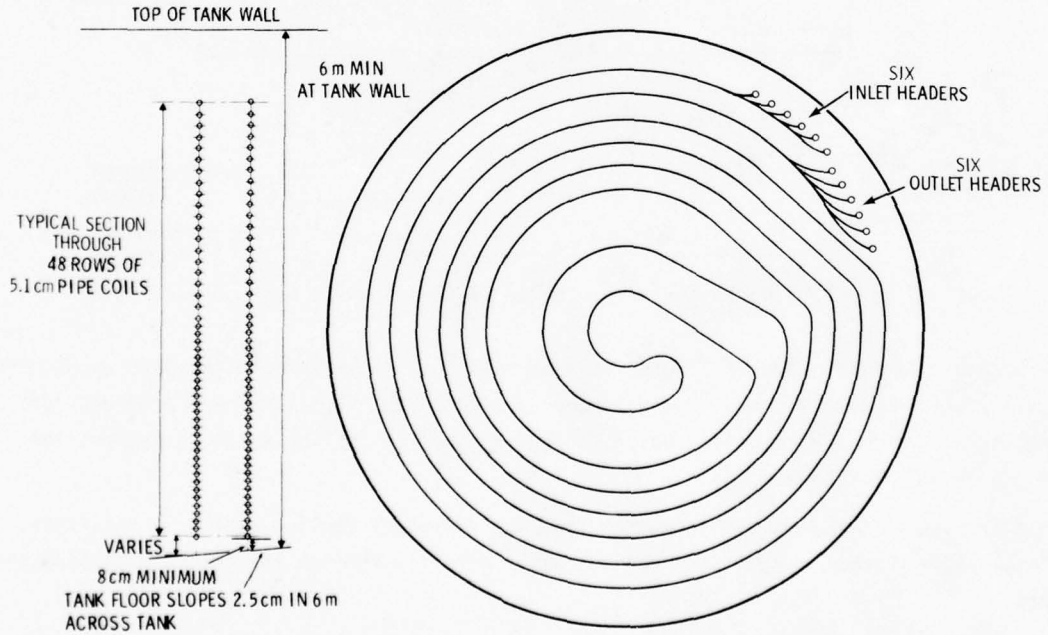


FIGURE 5.1.12. Tank Cooling Coil Arrangement, Top and Cross-Section Views

of the six banks is out of service, the remaining five banks will maintain a full tank at peak heat load at 60°C or below. The cooling systems for the lower heat load tanks are similar; fewer internal coils, however, are provided.

Three separate cooling water supplies are provided. The cooling system is designed to provide sufficient cooling during all credible events. A schematic of the cooling system is shown in Figure 5.1.13. The first system, used during normal operation, is a closed cooling tower loop. Heat from the closed primary coolant loop is rejected through plate-type heat exchangers to the cooling tower loop. The water pressure for the spray tower cooling in the plate-type exchangers is higher than that of the waste tank cooling water to minimize the chance of contaminating the spray tower cooling water in the event of a coil leak. Spare cooling water pumps are on emergency power. To determine when a leak occurs in a waste tank coil, a surge tank is installed on the intake side of the cooling water pumps at a height that provides cooling water pressure in the coils greater than the maximum hydrostatic pressure from a full tank of HLLW. Should a coil leak occur, the water level in the surge tank decreases.

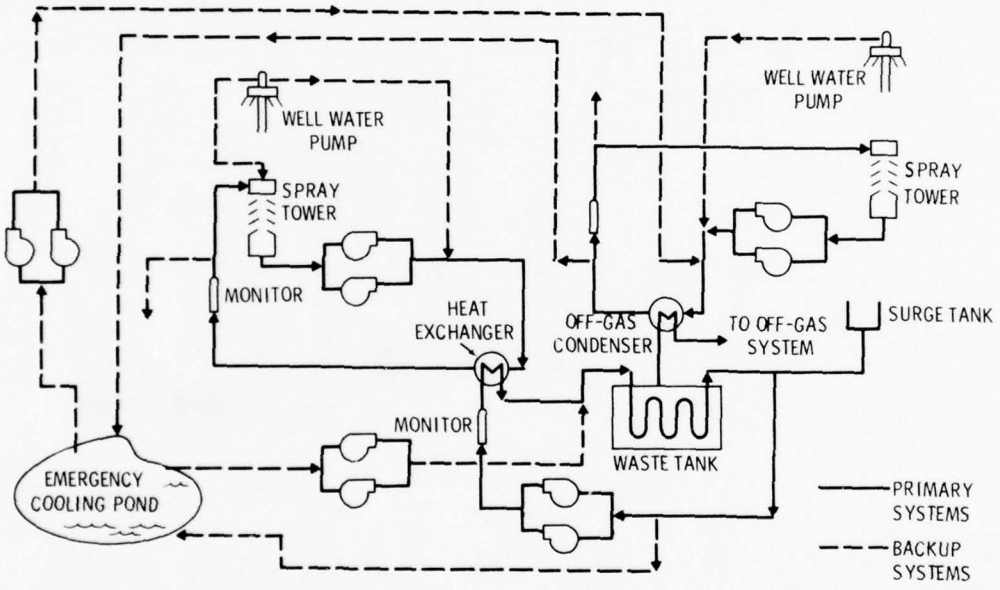


FIGURE 5.1.13. Cooling Systems for High-level Liquid Waste Storage Facilities

The second system provides well water on a once-through basis through the heat exchangers. In the unlikely event that the well water becomes contaminated, facilities are provided for diverting the effluent to a retention basin (capacity equal to cooling water throughput for 1 day of operation) for cleanup.

The third system provides cooling water from the emergency cooling pond. In this case, spare diesel-powered pumps recycle the cooling water directly through the coils, bypassing the exchangers.

Waste Tank Ventilation. The ventilation system is designed to provide sufficient air to maintain the hydrogen below ~1% by volume (~25% of lower explosive limit). The requirement for purging the vapor space is met with exhaust blowers that, even when "dead headed," will not produce pressure drops across the empty container in excess of the structural limitations. As

backups, a pressure regulation system and a pressure/vacuum relief device are provided. The pressure/vacuum relief device is set to vent the tank to the vault in the event pressures exceed a vacuum of 25.4 cm (10 in.) of water or a pressure of 7.6 cm (3 in.) of water. Instruments are provided for continuously measuring the concentration of hydrogen and organic vapors in the tank vapor space.

The annular space between the primary and secondary containers is vented to a cell in the FRP. No ventilation air is supplied to the annulus; it merely rides as a "dead-headed" surge on the cell ventilation and thus is maintained at a slightly negative pressure.

Waste Tank Agitation. Two types of agitation systems are used to keep particulate matter in suspension and thereby reduce the accumulation of solids on the bottom of the tanks. Airlift circulators are used for continuous vertical mixing of the tank contents, and ballast tanks are provided intermittently to sweep the tank bottom. Both types of agitators are pneumatically operated and are supported from the tank top. The airlift circulators provide ventilation air and are the principal means for in-tank concentration through evaporation. These agitation techniques have been used effectively by the British.[5,8]

An airlift circulator is diagrammed in Figure 5.1.14. The vertical air supply line supports an outer pipe 46 cm (18 in.) in diameter. The bottoms of both the diffuser cone and

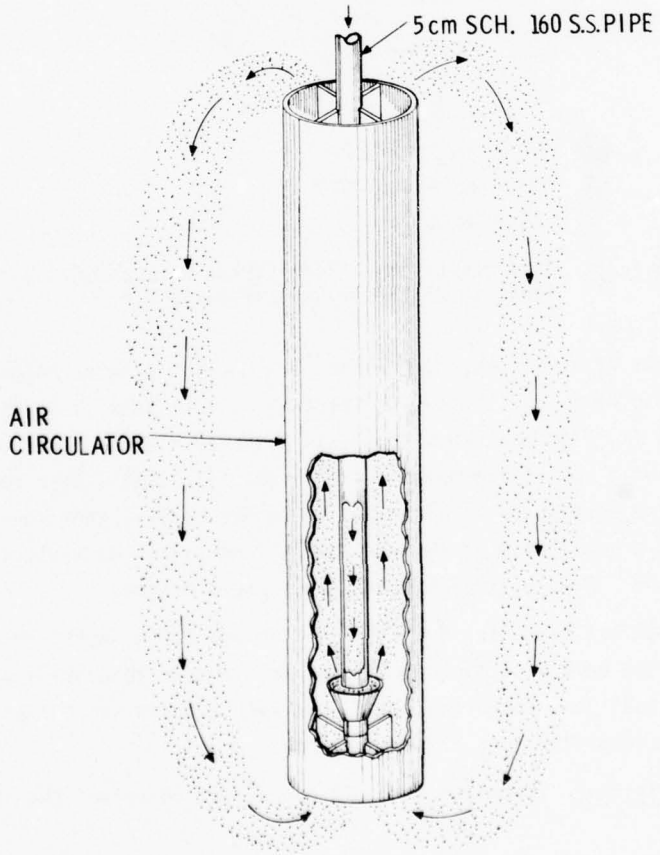


FIGURE 5.1.14. Airlift Circulator

outer pipe are positioned a minimum of 46 cm above the floor of the tank. Half of the outer pipes are 0.9 cm (3 ft) high and half are 2 m (7 ft) high, to provide for different levels during filling. A total of 22 airlift circulators are installed in each HLLW tank as shown in Figure 5.1.15.

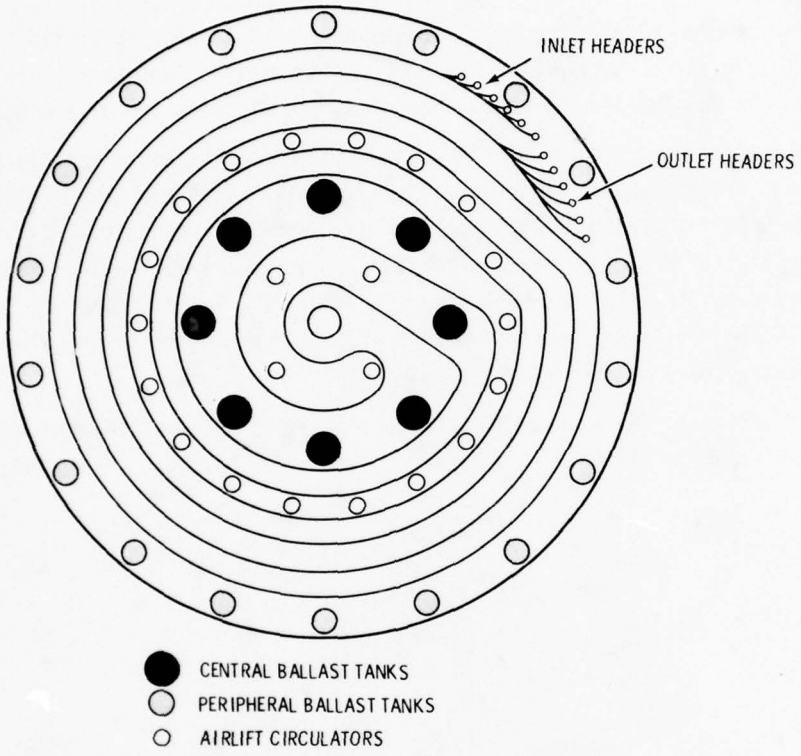


FIGURE 5.1.15. Arrangement of Airlift Circulators and Ballast Tanks in High-level Liquid Waste Tank

The ballast tanks are of two types, central and peripheral. The arrangement of these tanks is also shown in Figure 5.1.15. A typical central ballast tank is shown in Figure 5.1.16. Each of these is 5 m (16 ft) high and 0.9 m (3 ft) in diameter. Air to each ballast tank is supplied intermittently at a controlled pressure for a specific time. This results in a flushing action. When the supply air is off, the air in the ballast tank vents to the HLLW tank vapor space through a small hole in the air supply line, allowing waste solution to flow back into the ballast tank. Nine central ballast tanks are provided.

The 18 peripheral ballast tanks are 5 m (16 ft) high and 0.6 m (2 ft) in diameter. As shown in Figure 5.1.17, the bottom section terminates in a nozzle to provide a directed flow of solution to the tank wall just above the floor. As with the central ballast tanks, air is supplied intermittently, resulting in a flushing action.

Waste Tank Off-Gas System. The waste tank off-gas system comprises the following components:

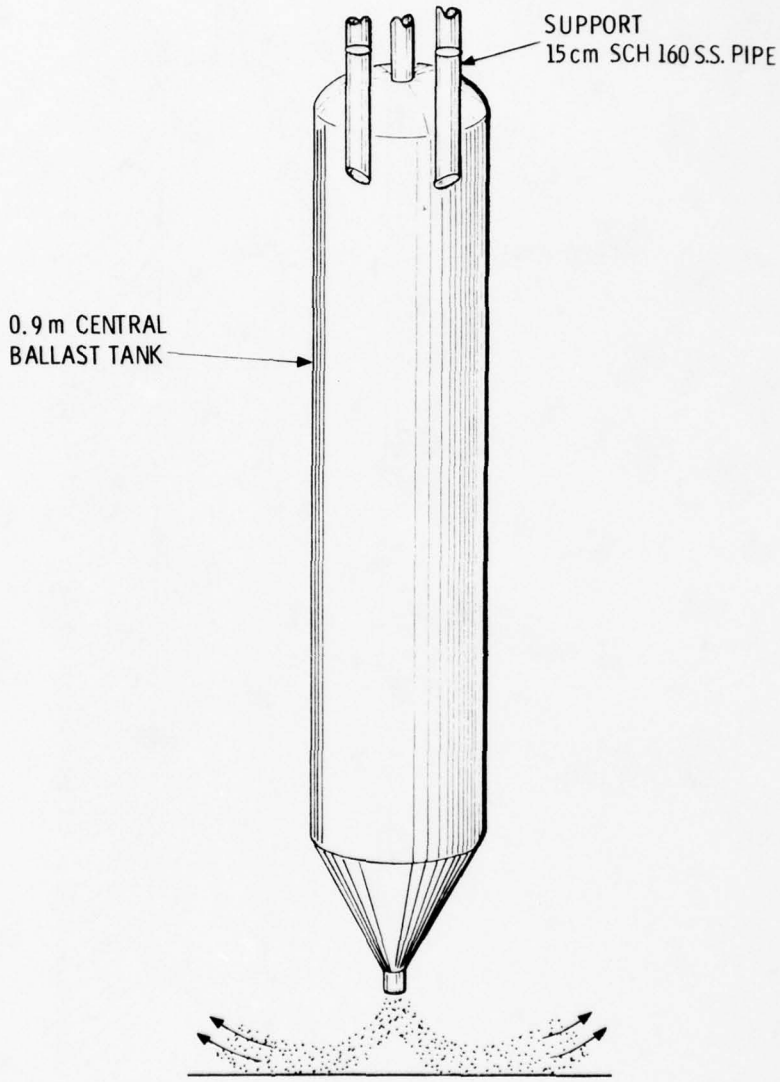


FIGURE 5.1.16. Central Ballast Tank

Off-Gas De-entrainer. The HLLW tank is vented at the top through a 36-cm (14-in.) dome that contains a 10-cm (4-in.) -thick wire mesh separator to minimize entrainment in the off-gas.

Condenser and Knockout Pot. Each HLLW tank is provided with an off-gas condenser and a knockout pot. A waste tank off-gas condenser is capable of cooling the off-gas from a boiling tank [BP 104°C (∿219°F)] to 38°C (100°F), assuming available cooling water at a temperature of 29°C (85°F). During normal operation the off-gas enters the condenser saturated at 60°C (140°F) and is cooled to 38°C. As shown in Table 5.1.8, the size of the off-gas condensers vary with the waste tank heat rejection capability. The cooling system for the off-gas condensers, shown

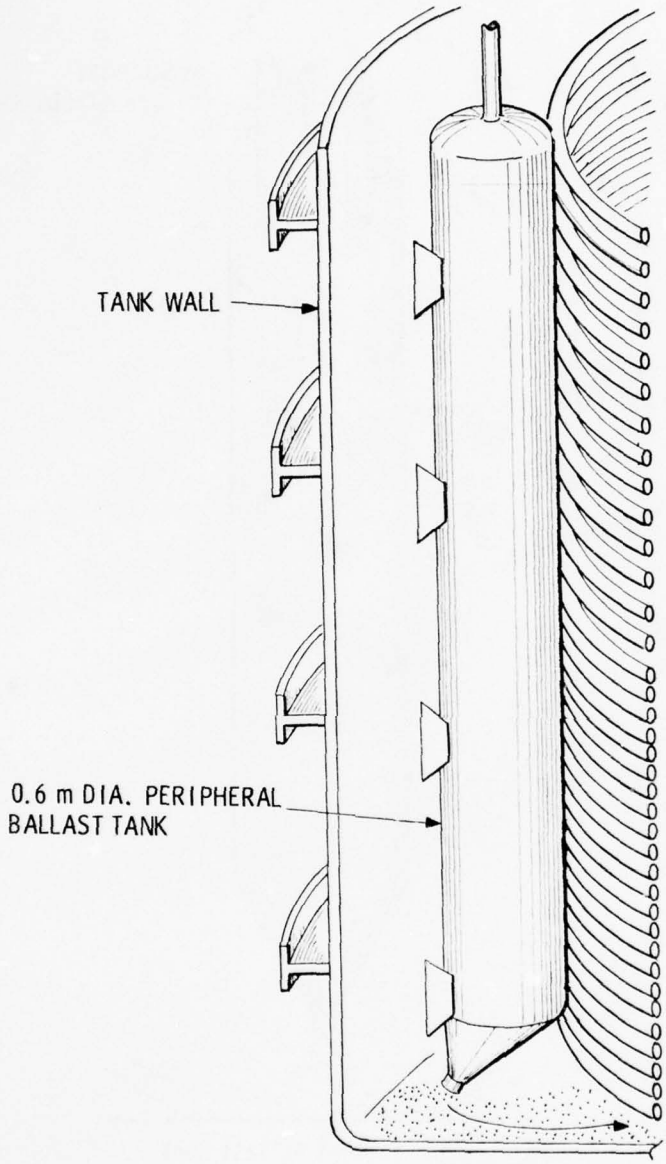


FIGURE 5.7.17. Peripheral Ballast Tank

in Figure 5.1.18, comprises three separate cooling water supplies. The primary system, used during normal operation, is a closed cooling tower loop. This system is independent of the cooling tower loop provided for the waste tank cooling coils. The primary backup system supplies well water on a single-pass basis and is also independent of that provided for the waste tank. The other backup system furnishes cooling water from the emergency cooling pond.

The airflow and vapor condensate from the waste tank off-gas condenser enter a knockout pot which provides liquid-gas separation. The off-gas exits the knockout pot through a 15 cm (6 in.) thick wire mesh separator and is routed for disposal to either the FRP vessel off-gas

TABLE 5.1.8. Waste Tank Off-Gas Condenser and Knockout Pot Data

HLLW Tank No.	Waste Tank Cooling Capacity, MW	Off-Gas Condenser Size, m^2 Heat Transfer Area	Knockout Pot Size, Dia. (Height, 1.1 m)
1	11.4	14	0.3
2	11.4	14	0.3
3	7.9	10	0.24
4	7.9	10	0.24
5	5.7	7	0.2
6[a]	11.4	14	0.3

a. Spare tank.

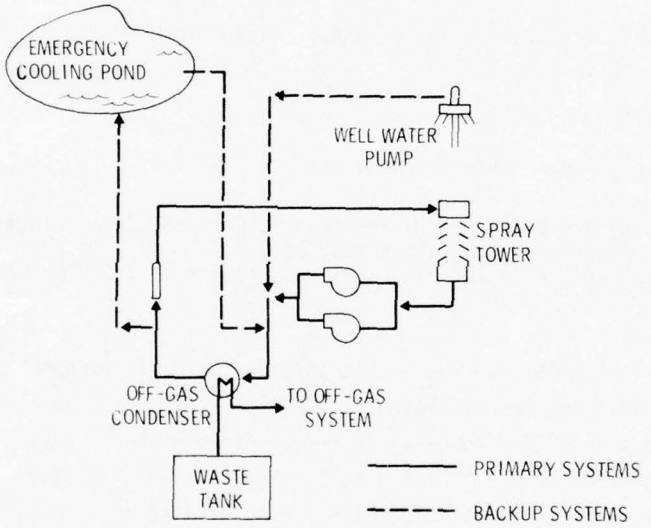


FIGURE 5.1.18. Off-Gas Condenser Cooling Systems

system or the waste tank off-gas system. The condensate from the knockout pot can be routed to the HLLW tank, to the HLLW diversion equipment, or to the FRP general purpose concentrator. This permits in-tank concentration or allows the condensate to be returned to the tank. As in the case of the off-gas condensers, the size of the knockout pots and demisters required varies with the heat rejection capability of each waste tank, as also shown in Table 5.1.8.

Superheater. Airflow from the waste tank knockout pots enters the superheater at 38°C (100°F) and is superheated by condensing steam to 125°C (257°F). The superheater has a heat transfer area of 38 m^2 (410 ft^2). A spare unit is provided.

Iodine Adsorber. The off-gas iodine adsorber is a bed of silver zeolite 0.75 m (2.5 ft) in diameter and 0.9 m (3 ft) deep. The silver zeolite adsorber provides a decontamination factor for iodine removal of greater than 1000. Design data for the adsorber are given in Table 5.1.9. Parallel units, which enable one unit to operate while the other is out of service, are required and are designed for ease of bed replacement (remotely, if radiation levels dictate).

TABLE 5.1.9. Design Information for Silver Zeolite Iodine Adsorber

Assumptions

NO_x concentration <5%

H_2O vapor <5%

Design Criteria to Achieve Decontamination Factor (DF) of 10^3

Loading capacity[a] - 50 mg I_2/g AgX

Minimum residence time - 0.6 sec (at STP)

Minimum bed depth - 10 cm[b] (~4 in.)

Temperature - 125°C (257°F)

Air bypass - limited to <0.1% of total flow to achieve DF of 10^3

Sorbent - fully exchanged, $AgNO_3$ treated Linde molecular sieves, Type 13X, 0.16 cm (1/16 in.) pellet

Sorbent density - ~0.85 g/cm^3

Pressure drop - use ΔP data for zeolites

a. Loading capacity can be increased at lower superficial face velocities (e.g., at 30 m/min loading is about doubled).
b. The actual bed depth will depend on how much iodine is taken out before regenerating bed.

Exhaust Filters. Airflow from the iodine adsorber is drawn through a roughing filter and then through a high-efficiency particulate air (HEPA) filter before being discharged by the exhaust blower to the stack. The roughing filter consists of three dust-stop filters in parallel, each with an area of 0.4 m^2 (~4.3 ft^2). The HEPA unit consists of three standard HEPA filters (about 61 x 61 x 29 cm) in parallel, each with 18 m^2 (200 ft^2) of filtration area. Parallel units designed for ease of replacement (remotely, if radiation levels dictate) are required. Testing connections for inserting dioctylphthalate aerosol are required to enable periodic HEPA filter efficiency measurements. The airflow to the filters must be maintained at a temperature ~20°C (36°F) above its dew point to avoid plugging the filter with water vapor.

Exhaust Blower. The exhaust blower is sized to handle the off-gas flow from the entire waste tank storage facility. A spare blower and emergency power are provided.

The superheater, iodine adsorber, exhaust filters and exhaust blower are common to all HLLW tanks and are sized accordingly.

HLLW Transfer. Intertank transfers and transfers to the waste solidification plant are made with steam-jet eductors, which are located in each waste tank. Connections are made using flow diverters. Primary waste tanks are equipped with two main jets and two installed spares, each of which is capable of delivering 1.7 x 10^4 ℓ/hr (75 gpm) in service with 110 atm. (150 psig) of steam. Waste tank annuli have one installed 75-gpm jet.

Instrumentation. The HLLW tanks and auxiliaries are equipped with a number of monitoring systems to assure that the facility is operated within prescribed limits. Critical monitoring systems are of such integrity and redundance that the probability of loss of surveillance is very low. The instrumentation systems are listed in Table 5.1.10.

TABLE 5.1.10. Monitored Parameters for High-level Liquid Waste Tanks and Auxiliaries

- Temperature

  Tank contents
  Primary container bottom and wall
  Off-gas entering and exiting condenser and exiting the knockout pot
  Off-gas exiting the superheater, iodine adsorber, roughing filter and HEPA filter
  Cooling water entering and exiting tank coils, heat exchangers and condenser
  Condensate exiting knockout pot

- Pressure

  Vapor space (pressure regulation control system required)
  Primary coolant to waste tank coils
  Secondary coolant to exchangers
  ΔP across demister
  ΔP between vapor space and annulus
  ΔP across knockout pot
  ΔP across iodine adsorber
  ΔP across roughing filters
  ΔP across HEPA filters

- Liquid Level

  Primary container (within $\sim$0.16 cm)
  Annulus sump
  Coolant surge tank

- Specific Gravity of HLLW

- Flow

  Cooling water to condenser, tank coils and heat exchangers
  Air to agitation system (airlift circulators and ballast tanks)
  Vapor space air purge

- Hydrogen and Organic Vapor Content of Vapor Space

- Radioactivity

  Exhaust air from HEPA filters
  Primary coolant from coils
  Secondary coolant
  Condensate from knockout pot

- Radiation Detection

  Gamma monitor with minimum detection level of 1 mR/hr above waste tank

Waste Tank Equipment Building. A separate building, designed to withstand the stresses imposed by design basis natural phenomena, houses most of the auxiliary equipment, services, and

controls for the HLLW tank storage facility. This building, termed the waste tank equipment building (WTEB), is approximately 35 m (115 ft) square and is divided into three main sections: a cold (nonradioactive) area, an intermediate radiation level area, and a hot (high radiation level) area.

The cold area of the WTEB houses the instrumentation required for the waste tank complex. This instrumentation includes liquid level, density, temperature, pressure, and flow recorders and alarms, hydrogen and organic vapor sensors, and radioactivity monitors.

The intermediate area of the WTEB provides all the services required by the waste storage facility except the off-gas system and instrumentation. Included in this area are the tank cooling system, the sampling system, the airlift circulator and ballast tank air supply and control systems, and the emergency steam generator. Concrete shielding, 0.15 m (0.5 ft) thick, is provided for personnel protection.

The hot area of the WTEB houses the off-gas system. This equipment includes the waste tank off-gas condensers, knockout pots, superheaters, iodine adsorbers, roughing filters, and HEPA filters. Concrete shielding, 0.3 m (1.0 ft) thick, is provided for personnel protection. Equipment is provided to either transfer off-gas condensate to the FRP for further treatment by evaporation.

High-level Liquid Waste Flow Diversion and Transfer Equipment. Diversion equipment is provided for interconnecting waste transfer pipelines. The waste flows by gravity from the FRP and is routed through the diverter tank by way of a rotating outlet to a selected tank. The waste flows by gravity from the diverter to the HLLW storage tank. Figure 5.1.19 illustrates the flow diverter. This equipment is housed in a concrete cell below the WTEB. The diverter cell is lined with stainless steel to provide double containment. A collection sump fitted with liquid level instrumentation and transfer jets is provided to move the waste from the sump back to the diverter. All waste transfer lines in the HLLW storage facility are double-wall construction. The secondary containers, the pipe vaults, drain to leak detection sumps for detection of leaks in primary lines. All waste transfer lines are provided with a backup spare line.

Storm Sewers. A storm sewer is provided to collect surface water runoff. The effluent from the storm sewer system is monitored continuously for radioactivity. Capability is provided to divert the flow to a retention basin in the event that the effluent becomes contaminated. The storm sewer will be constructed of concrete pipe in the vicinity of the FRP. If open ditches are used elsewhere, they will be lined with concrete.

Waste Sampling. Stored and fresh HLLW can be sampled by transferring the waste to the flow diverter, which is equipped with a remote sampler. Provision is also made for remote sampling of the sump in the tank vault. The tank off-gas can be sampled between the waste tank and the waste tank off-gas system.

Shielding and Remote Handling Equipment. The facility is designed for remote operation. Maintenance activities are normally performed using either contact or semiremote methods. There are two major radiation sources in the tank farm: the HLLW storage tanks and related equipment, and the storage tank off-gas treatment equipment in the WTEB. The storage tanks

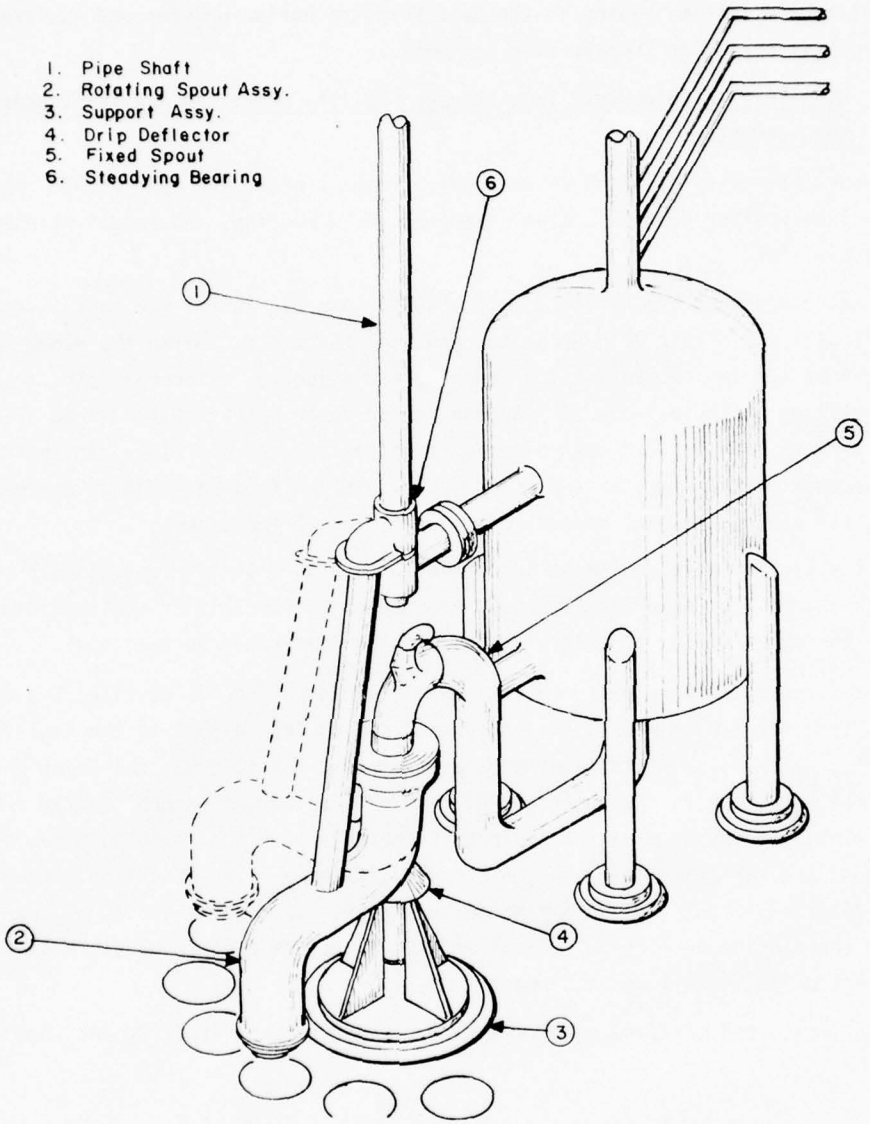


FIGURE 5.1.19. Flow Diverter

are buried in the ground. Operating personnel in the tank farm area are shielded from the HLLW radiation by the 1.5-m (5.5-ft) thick concrete tank roof and by more than 3 m (10 ft) of earth. This shielding reduces the maximum dose rate at the ground surface to $\leq$1 mrem/hr. This area is not normally occupied by operating personnel. Personnel are admitted to this area only for infrequent maintenance activities and some instrument readings.

The equipment for off-gas treatment is housed in a shielded portion of the WTEB. The shielding consists of 0.15 to 0.46 m (0.5 to 1.5 ft) of reinforced concrete or the equivalent and reduces the radiation in normally occupied areas of the WTEB to $\leq$1 mrem/hr, and to $\leq$10 mrem/hr in areas that are not normally occupied.

HLLW routing and off-gas piping in the tank farm are buried underground and are shielded to the same equivalent as the storage tank contents.

5.1.1.5 High-level Liquid Waste Tank Storage Facility Operating and Maintenance Requirements

The reference facility operates 24 hr a day, 7 days a week, the year round. Normal activities include monitoring tank status, sampling, HLLW routing, and normal maintenance and replacement activities.

Few special procedures are needed to place waste in a new tank. The tank is filled one-third full of 1.0 M nitric acid prior to receiving the waste. After the waste has entered the tank, airflows for tank agitation and sparging are adjusted, as appropriate, to prevent solids from settling or the buildup of hydrogen in the vapor space. Nitric acid is periodically added to the tank to replace acid destroyed by radyolsis and to maintain a minimum concentration of 1.0 M. The tank contents may be transferred by steam jet from one tank to another in order to make efficient use of the heat removal characteristics of the tanks.

Other activities involve equipment adjustments, such as diverter repositioning, HLLW routing jumper changes, or pump installation, are performed remotely or semiremotely using cranes and/or shadow shielding to control the radiation dose rates to personnel.

Semiremote or remote techniques are usually used in handling failed tank farm equipment that has been in contact with HLLW. The equipment is contained either in the tank, a vault, or a shielded pit. After flushing the equipment and removing the concrete shielding covers where appropriate, the equipment is disconnected remotely with an impact wrench mounted on a crane (mirrors or television may be used for indirect sighting). Contact techniques may be used for this maneuver if the radiation level is low enough. If there is no danger of contamination spread, the failed equipment is decontaminated by spraying on removal and is placed in a failed equipment box for storage or disposal. Similar techniques are used to handle failed off-gas system equipment or to install new equipment.

Staffing. Estimated staffing requirements for the reference facility are shown in Table 5.1.11.

TABLE 5.1.11. High-level Liquid Waste Tank Storage Facility Staffing Requirements

Job Description	Personnel Required, man-yr/yr
Operators	9
Radiation monitors	2
Maintenance craftsmen	7

Supplies and Utilities. Table 5.1.12 shows the supplies used in tank farm operations. Table 5.1.13 lists the utilities required to operate the tank farm.

TABLE 5.1.12. High-level Liquid Waste Storage Facility Supply Requirements

Supply	Use	Annual Requirement, m^3
Nitric acid (12.2 M)	Decontamination and waste tank acid makeup	95
Silver zeolite	Iodine sorption	0.042

TABLE 5.1.13. High-level Liquid Waste Storage Facility Utility Requirements

Utility	Use Rate	Annual Requirement
Electricity	1010 kW	8.8×10^6 kWh
Water consumed	1.1×10^6 kg/day	4.1×10^8 m^3
Steam	2700 kg/day	1×10^6 kg
Oil	2 ℓ/day	0.73 m^3
Gasoline	4 ℓ/day	1.5 m^3

Hazardous Materials. Except for the HLLW, the only hazardous materials used in the tank farm operation are industrial chemicals, such as nitric acid, used for decontamination and some organics. Nitric acid is also used as a chemical addition to the waste tanks to adjust radiolytic decomposition losses. Radiolytic hydrogen generated in the tank is maintained at less than one-fourth of the theoretical explosive limit. This is done by using two independent systems, the airlift circulation air and tank purge air. If these two dilution sources were lost, the tank would still be safe since there is no ignition source in the tank. A hydrogen monitor is provided for the tank off-gas to determine the hydrogen level in the tank atmosphere.

5.1.1.6 High-level Liquid Waste Tank Storage Facility Secondary Radioactive Wastes

Secondary radioactive wastes associated with the tank storage facility are shown in Table 5.1.14.

5.1.1.7 High-level Liquid Waste Tank Storage Facility Emissions

Facility emissions are characterized in Table 5.1.15.

5.1.1.8 High-level Liquid Waste Storage Facility Decommissioning Considerations

It is projected that at the end of the reference facility's operating life, the empty tanks, waste tank equipment building, and the associated equipment will be contaminated with 30 MCi of mixed fission products with a 3-year equivalent time out of reactor. Plans for decontaminating and decommissioning the tank farm must provide for appropriate decontamination equipment and systems and for monitoring and recording equipment needed to assess contamination levels. Ease of retirement and removal will be an important consideration in selecting all materials and equipment for the facility. Any facility structure surfaces that are highly susceptible to hard-to-remove radionuclide contamination will be covered with a removable surface.

TABLE 5.1.14. High-level Liquid Waste Storage Facility Secondary Radioactive Wastes

Description	Volume, m^3/yr	Radioactivity Factors[a]	
Combustible and compactable waste	43	All	5×10^{-10}
Failed equipment	27	All	5×10^{-10}

a. Fraction of inventory activity per year in secondary wastes. For inventory use column 2 of Table 5.1.4 and 8,000 or 10,000 MTHM-equivalent inventory for 4-year or 5-year storage respectively.

TABLE 5.1.15. High-level Liquid Waste Storage Facility Emissions

Emission	Description	Annual Quantity	Annual Radioactivity Release Factors[a]
Gaseous	Waste tank off-gas, T = 125°C	Air 2.5×10^7 m^3	^3H 1×10^{-1}
		NO 2.2×10^4 kg	^{129}I 1×10^{-4}
		NO_2 2.0×10^5 kg	Ru 1×10^{-12}
			All others 1×10^{-13}
	Building ventilation air	4.0×10^8 m^3	
	Minor accident integrated annual release		None identified
Cooling tower water:			
	Evaporated, T = 38°C	3.5×10^8 kg	
	Drift, T = 38°C	1.7×10^6 kg	
	Blowdown, T = 27°C	6.1×10^7 kg	
Other	Heat	2.4×10^5 MW-hr (8.1×10^{11} BTU)	

a. Fraction of inventory activity released per year. For inventory use column 2 of Table 5.1.4 and 8,000 MTHM-equivalent inventory for 4-year storage or 10,000 MTHM-equivalent inventory for 5-year storage. Release includes a DF of 10^7 in vessel off-gas system where applicable.

The tank farm will be designed and constructed so that it will have a useful operational life of 100 years based on the following design considerations:

- Every component will be designed for maintenance under operating conditions or for a 100-year operating life.
- A quality assurance program will be applied to all aspects of design, procurement, construction, and operation.
- Materials will be of known durability, and allowances will be made for radiation damage, corrosion and wear.

5.1.1.9 High-level Liquid Waste Storage Facility Postulated Accidents

Postulated minor and moderate accident scenarios for the reference HLLW tank storage facility are given in Tables 5.1.16 and 5.1.17.

Although there have been leaks from some of the nonstress relieved carbon steel tanks storing caustic defense waste, no leaks in stainless steel tanks storing acidic HLLW have been observed to date.(2)

TABLE 5.1.16. High-level Liquid Waste Tank Storage Facility Minor Accidents

Accident No. and Description	Sequence of Events	Safety System	Release
5.1.1 – Loss of normal electrical power. Expected frequency ∿1 per year.	1. Power to substation supplying waste storage facilities interrupted.	1. Emergency power diesel generator (several redundant emergency power supplies) available from offsite sources.	None
5.1.2 – Leak from diversion equipment. Expected frequency ∿1 per year.	1. Spout misaligned or defective weld causes leak. 2. Waste transfer stopped. 3. Cell decontaminated and leaking component repaired.	1. Liquid collection sump 2. Redundant continuous leak detection instrumentation and alarm.	None
5.1.3 – Temporary loss of sparge/purge air. Expected frequency ∿3 per year.	1. Compressor supplying sparge/purge air to waste tank fails.	1. Redundant air supply and control system.	None
5.1.4 – Loss of normal secondary coolant supply. Expected frequency ∿0.2 per year	1. Spray cooling tower fails.	1. Two backup cooling water supplies. Pressure/temperature control system.	None
5.1.5 – Temporary loss of exhaust blower. Expected frequency ∿0.5 per year.	1. Exhaust blower in waste tank off-gas system fails 2. Sparge/purge air momentarily overpressures primary container. 3. Pressure in tank is reduced to normal operating level and relief device reseals.	1. Spare exhaust blower. 2. Pressure/vacuum device vents primary to secondary. Secondary vented to a process cell.	None

TABLE 5.1.17. High-level Liquid Waste Tank Storage Facility Moderate Accidents

Accident No. and Description	Sequence of Events	Safety System	Release
5.1.6 – Filter fire. Expected frequency ~0.05 per year.	1. Organics enter waste tank. 2. Organics in off-gas condense on roughing and HEPA filters. 3. Spark ignites organics in HEPA filter. 4. Filter burns and activity enters off-gas.	1. Organic separation decanter upstream of HLLW evaporator (and applicable scenario). 2. Off-gas condenser, knockout pot and superheater are explosion proof. 3. Off-gas radioactivity monitors and alarm. 4. Off-gas rerouted through spare HEPA filter or backup off-gas system. 5. Activity released from burning filter removed by FRP APS.	<1 g high-level waste calcine equivalent released to FRP atmospheric protection system (APS).
5.1.7 – Breach of waste tank (primary container) with sound secondary liner. Expected frequency is ~0.006 per year at the 95% confidence level (based on no observed failures in stainless steel tanks to date).	1. Primary liner breached due to crack at weld, material flaw or corrosion. 2. Waste drains to leak detection to sump. 3. Contents of primary and secondary containers transferred to spare tank.	1. Tank material is traceable and inspected before construction. All welds are 100% x-rayed and leak checked. Waste is composition and temperature controlled, and agitated to prevent settling. The tank has a stainless steel secondary liner with a leak collection sump between and redundant primary liquid level instrumentation and alarms. 2. The sump has redundant leak detection instruments and alarms. Secondary liner floor is periodically flushed to the sump to detect small leaks. 3. Spare tankage. 4. Redundant transfer jets in the primary tank and in the secondary collection sump.	None
5.1.8 – Off-gas HEPA filter fails. Expected frequency is 0.06 per year.	1. Particulate activity bypasses filter. 2. Off-gas rerouted to spare HEPA filter or backup off-gas system. 3. Failed filter replaced.	1. Redundant continuous radioactivity monitors and alarms. 2. Off-gas rerouted to backup off-gas system or spare HEPA filter. 3. Activity that bypasses HEPA removed by FRP APS.	<0.1 g HLW calcine equivalent released to FRP APS.

Design features of the waste storage tank preclude credible scenarios of hydrogen explosions or of sustained loss of cooling. Studies on cooling water interruption in HLLW tanks indicate that following a cooling water interruption, self-heating will bring the waste to the boiling point in 7 hr, with the waste boiling dry in about 100 hr.[9,10] Within this time the incident can be controlled by assuring proper off-gas treatment, resuming cooling water flow, and adding makeup water when needed. Several reliable independent cooling and makeup water supplies are present. The staff will be trained to take immediate action to assure a cooling water supply. There is more than ample time for this action. Credible cooling water interruptions are included in the minor category since no release will occur (loss of normal electrical power, loss of normal secondary coolant supply). A hydrogen explosion requires both an accumulation within flammable limits and an ignition source. The tank facility is designed to prevent hydrogen accumulation and ignition by the use of redundant air purge systems. Spark-proof construction will be used. Design redundancy and equipment reliability in this system make hydrogen explosion scenarios noncredible accidents.

No accidents that could be classified as severe accidents could be realistically postulated for this technology.

5.1.1.10 High-level Liquid Waste Tank Storage Facility Costs

Estimates have been made, in mid-1976 dollars, of capital, operating and levelized unit costs. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate is shown in Table 5.1.18. This estimate provides for a 4-year storage capacity. To develop the capital cost for a 5-year storage period, assume a scaling factor of 0.8 [5-year cost = 4-year cost x $(7/6)^{0.8}$]. Table 5.1.18 presents all capital costs specifically resulting from including the HLLW tank storage, with its associated facilities, as an integral part of the FRP described in Section 3.2. These costs also include the effect of additions to the utility supplies, such as electrical substation; heating, ventilation, and air conditioning (HVAC); and compressed air; as well as the cable, piping, instrumentation, and other bulk materials incorporated directly into the HLLW tank storage facility. General FRP capital costs for such services as laboratories, warehousing, and shops, however, are not allocated to the HLLW tank storage capital cost.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation, with the exception of working capital.

Operating Cost. The reference facility's annual operating cost for 4-year storage is shown in Table 5.1.19. Direct estimates have been made of operating labor, process materials and utilities using the manpower materials, and utilities requirements given in Table 5.1.11 though 5.1.13. Annual maintenance materials costs are estimated at 3% of the initial equipment investment.

Miscellaneous costs include supplies and equipment and outside support services. Nitric acid, silver zeolite, and water treatment chemicals are considered significant cost items, have been estimated individually, and are added to the miscellaneous costs.

TABLE 5.1.18. High-level Liquid Waste Tank Storage Facility Capital Cost Estimate

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		30	47,100	400	47,500
Buildings and structures		610	6,600	7,300	13,900
Bulk materials		1,810	30,300	21,700	52,000
Site improvements		150	8,600	1,800	10,400
Subtotal of direct site construction costs		2,600	92,600	31,200	123,800
Indirect site construction costs	680	520	11,600	15,000	26,600
Total field cost	680	3,120	104,200	46,200	150,400
Architect-engineer services					29,600
Subtotal					180,000
Owner's cost					60,000
Total facility cost					240,000
Estimate accuracy range					±20%

TABLE 5.1.19. High-level Liquid Waste Tank Storage Facility Operating Cost Estimate

Cost Element	Annual Costs, $1000s
Direct labor	970
Process materials	0
Utilities	180
Maintenance materials	1900
Overhead	1700
Miscellaneous	900
Total	5650 +50% -25%

The operating cost estimates include treatment of both primary and secondary wastes. The estimates for the miscellaneous items are assumed to include all unidentified operating costs. The costs of taxes, insurance, and interest, however, are included in the capital segment of the levelized unit cost.

Levelized Unit Costs. The levelized unit cost, including levelized capital and operating costs, is shown in Table 5.1.20. The unit cost calculation assumes private ownership of the facilities. Costs for both 4-year and 5-year storage are shown.

5.1.1.11 High-level Liquid Waste Tank Storage Facility Construction Requirements

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating this impact.

TABLE 5.1.20. High-level Liquid Waste Tank Storage Facility Levelized Unit Cost Estimate

Cost Element	Unit Cost, $/kg HM	
	4-yr Storage	5-yr Storage
Levelized capital charge	30.00	33.00
Levelized operating charge	3.00	3.00
Levelized total unit cost	33.00 ±30%	36.00 ±30%

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of the HLLW tank storage is included in the overall schedule for the reference FRP. This schedule is given in Section 3.2.3. The field labor force estimated for the construction of the HLLW storage facility are as follows:

	Man-hours, 1000s
Manual field labor	3120
Nonmanual field labor	680
Total field labor	3800

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, material and services provided at the site of the HLLW storage facility, while offsite costs include all services, material, and equipment provided, fabricated, or assembled elsewhere. The distribution of total costs in these categories is as shown below:

	Costs, $1000s
Onsite	88,800
Offsite	151,200
Total	240,000

Site Requirements. No additional site requirements beyond those of the FRP are identifiable for the reference facility. Land commitments for the HLLW storage facility are included with those of the FRP.

Water. Approximately 4500 m^3 (12 x 10^6 gal) of water are required during the construction period.

Construction Materials. Materials committed to facility construction are:

Concrete	11,500 m^3	(15,000 yd^3)
Steel	6,200 MT	(6,800 tons)
Copper	14 MT	(15 tons)
Zinc	9 MT	(10 tons)
Aluminum	1.8 MT	(2 tons)
Lumber	700 m^3	(300 MFBM)

Energy. Energy resources used during construction are:

Propane	430 m^3	(114,000 gal)
Diesel	4,303 m^3	(1,140,000 gal)
Gasoline	2,900 m^3	(760,000 gal)
Electricity		
Peak demand		750 kW
Total consumption		2,170,000 kWh

Transportation Requirements. No transportation requirements for the HLLW storage facility construction have been identified beyond those for the FRP construction.

5.1.1.12 Effects of Fuel Cycles Options

The reference process for interim tank storage of HLLW assumes reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to HLLW interim storage.

No Recycle. Eliminating the fuel reprocessing operation does away with the generation of high-level liquid wastes. Accordingly, no HLLW storage facilities are required.

Uranium Recycle Only, with Plutonium to a Repository. This alternative is expected to generate about the same amount of concentrated HLLW as in the uranium and plutonium recycle case. The heat generated by the waste, however, would be slightly lower because fewer heat-generating actinides would be present. No significant change in the tank design would be necessary.

Uranium Recycle Only, with Plutonium to High-Level Waste (HLW). This alternative would also generate about the same quantity of concentrated HLLW as in the uranium and plutonium recycle case. The possibility of nuclear criticality in the storage tank, however, cannot be precluded if the plutonium is stored with the HLLW. Even if a neutron poison such as gadolinium were mixed with the HLLW, the risk of criticality would not be eliminated. For this reason, storing plutonium in HLLW tanks is not a viable alternative. The only practical procedure for this fuel cycle option is to store the HLLW and the plutonium separately until solidification. At the time of solidification, the plutonium can be mixed with the HLLW just ahead of or at the feed point of the HLLW calciner.

5.1.2 Physical Protection and Safeguards Requirements for High-level Liquid Waste Tank Storage

HLLW, when stored in tanks as described in Section 5.1.1.4, would be inaccessible to anyone considering theft. The HLLW's intense radioactivity and high heat release rates, the massive underground, thick-walled HLLW storage tanks, and the maze of facility support equipment make unauthorized transfer to a shielded container and offsite removal of the HLLW an incredible accomplishment, taking no account of the stringent physical protection measures that would have to be penetrated. For similar reasons, dispersal of HLLW onsite by explosives is not credible although the concentration of radioactive fission products in this waste may make it appear to be an attractive target.

With insider assistance, physical protection could possibly be breached, allowing acts of sabotage to the facility. The worst case would be a disruption of the tank cooling system and/or electrical system. Self-heating would cause the contents to begin to boil after 7 hr and to boil to dryness in 100 hr. The latter is not considered credible under the planned safeguards measures and in view of the discussion in Section 5.1.1.9. Some facility damage and a 300-ℓ (80 gal) spill to the ground during a 3 hr period (Accident 5.1.9) are considered to be representative of the most serious results from the worst act of sabotage.

HLLW, as a part of an FRP, would receive the physical protection provided for a vital area (Section 3.9.1).

REFERENCES FOR SECTION 5.1

1. Title 10, Code of Federal Regulations, Part 50 (10 CFR 50).

2. Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle, ERDA 76-43, Energy Research and Development Administration, Washington, DC, Vol. 3, Section 19, May 1976.

3. Barnwell Nuclear Fuel Plant Separations Facility: Final Safety Analysis Report. USNRC Docket-50332, Allied-Gulf Nuclear Services, Barnwell, SC, Sections 8 and 9, October 10, 1973.

4. B. M. Legler and G. R. Bray, "Concentration and Storage of High Level Liquid Waste at Allied-General Nuclear Services." Radioactive Wastes from the Nuclear Fuel Cycle, AIChE Symposium Series, 72(154):102, 1976.

5. D. W. Clelland, "High-Level Radioactive Waste Management in the United Kingdom." Proceedings of the Symposium on the Management of Radioactive Wastes from Fuel Reprocessing, Paris Nov. 27-Dec. 1, 1972, Organization for Economic Cooperation Development, Washington, DC, 1973.

6. Nuclear Fuel Recovery and Recycling Center: Preliminary Safety Analysis Report. Docket 50-564, Chapter 6, Exxon Nuclear Company.

7. K. J. Schneider, "Solidification and Disposal of High Level Radioactive Wastes in the United States." Reactor Technol. 13:384-415, 1970-1971.

8. B. F. Warner, A. S. Davidson, M. J. Larkin, and A. Naylor, "Operational Experience in the Evaporation and Storage of Highly-Active Fission Product Wastes at Windscale." Proceedings of the Symposium on the Management of Radioactive Wastes from Fuel Reprocessing, Paris, Nov. 27-Dec. 1, 1972. Organization for Economic Cooperation Development, Washington, DC, 1973.

9. Siting of Fuel Reprocessing Plants and Waste Management Facilities. ORNL-4451, Oak Ridge National Laboratory, Oak Ridge, TN, July 1970.

10. Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle: A Task Force Report. NUREG-0116, Nuclear Regulatory Commission, Washington, DC, pp. 4-162, October 1976.

5.2 STORAGE OF FUEL RESIDUE

5.2 STORAGE OF FUEL RESIDUE

Commercial experience in handling and storing fuel residue, which consists of leached cladding hulls and fuel assembly hardware, is limited to a single facility, Nuclear Fuels Services (NFS) in New York State. Fuel residues are classified here as a TRU waste, and it is assumed that they will ultimately be isolated in geologic repositories. Interim storage of packages of hulls and hardware (prepared as described in Section 4.2) would, therefore, be necessary. The fission and activation product radioactivity in the fuel residue necessitate remote handling and shielded storage of these wastes. Characteristics and contents of the reference fuel residue canister are given in Table 5.2.1.

Current concepts for interim storage of fuel residue specify placing it in canisters and storing the canisters in vaults or in subsurface caisson storage facilities. Some failed equipment packaged in identical canisters may be stored along with the fuel residue. A third option is to use spent fuel storage basins for storing both spent fuel bundles and fuel residue canisters. Exxon Nuclear Company plans to store residue canisters at their proposed fuel reprocessing plant (FRP) in the spent fuel storage basin, which has the design capacity to store about 7000 MT (7700 tons) of spent fuel.[1] Any of these interim storage methods could be implemented at either an FRP or at an independent site. Because the options of vault storage and subsurface caisson storage are representative of available technology, they have been selected for analysis in this report. Similar techniques have been used for retrievable storage of radioactive wastes at government installations.

Use of closed (welded) stainless steel canisters is assumed for containment of the residue whether in the compacted or uncompacted condition. These containers are compatible with all interim storage concepts as presently conceived. They would be more easily decontaminated than those made of concrete or carbon steel and would also offer maximum corrosion resistance. The use of vented canisters is questionable; any opening in the canister is a potential point for water to enter or radioactive nuclides to escape. Ingress of water would tend to increase the pyrophoricity of any Zircaloy fines present. The presence of a vent would also complicate the removal of smearable contamination from the canister's surface. Decontamination would probably be accomplished with high pressure water or steam. (See Sections 4.2.1 and 4.3.1 for additional information on canister design and quantities.)

The heat output from uncompacted fuel residue (i.e. fuel assembly hardware and hulls) produced via the reference flowsheet presented in Section 4.2 will be about 225W/1000 kg (300 W per canister of uncompacted residue) after 1.5 years of cooling, assuming a uniform mix of Zircaloy, stainless steel, and Inconel.[2] Most of the heat (>90%) is generated from the stainless steel and Inconel activation products in the hardware (see Tables 3.3.6 and 3.3.7). Thus, if these materials were separated from the Zircaloy hulls, as in the compaction and melting processes also discussed in Section 4.2, the canisters containing Zircaloy hulls would generate essentially no heat. The heat output from the canisters containing only stainless steel and Inconel would be about 1 W/kg or about 1 kW per canister. Failed equipment canisters are expected to generate less heat than canisters of uncompacted fuel residue. Adequate provision for heat removal would be

TABLE 5.2.1. Description of Reference Fuel Residue Canister

Canister size	0.76m dia x 3m long (30 in. x 10 ft)
Canisters per MTHM	0.24
Weight of hulls per canister	1110 kg (2450 lb)
Weight of hardware per canister	234 kg (516 lb)
Weight of sand per canister	1350 kg (2980 lb)
Weight of canister plus contents	3300 kg (7300 lb)
Isotopic heat generation[a]	300 W

Radioactivity Content, Ci/Canister[a]

Fission Products	
^{3}H	2.6×10^{2}
^{129}I	negligible
$^{90}Sr + ^{90}Y$	2.5×10^{2}
$^{95}Zr + ^{95}Nb$	2.3×10^{1}
$^{106}Ru + ^{106}Rh$	7.9×10^{2}
$^{134}Cs + ^{137}Cs + ^{137m}Ba$	6.3×10^{2}
$^{144}Ce + ^{144}Pr$	1.0×10^{3}
All other FPs	2.1×10^{2}
Total FPs	3.2×10^{3}
Actinides	
^{239}Pu	7.5×10^{-1}
^{241}Pu	3.8×10^{2}
Other Pu	1.4×10^{1}
$Cm^{242} + Cm^{244}$	3.5×10^{1}
All other actinides	1.9×10^{0}
Total Actinides	4.3×10^{2}
Activation Products	
^{55}Fe	1.7×10^{4}
^{60}Co	1.7×10^{4}
$^{95}Zr + ^{95}Nb$	7.1×10^{2}
All others	1.7×10^{4}
Total activation Products	5.2×10^{4}

a. As received for storage at an average 1.5 years out of reactor. Based on waste characterization Table 3.3.28. assuming uranium and plutonium recycle and 4.17 MTHM equivalent per canister.

required for canisters containing only the stainless steel and Inconel fuel hardware components; no special cooling would be necessary for canisters containing hulls only or uncompacted residue produced via the reference flowsheet.

5.2.1 Vault Storage of Fuel Residue

Canisters containing fuel residue could reasonably be contained in concrete vaults; the requirements for such a structure would include:

- adequate capacity
- adequate shielding for penetrating radiation
- interface capabilities with arriving and departing casks
- canister handling capability
- monitoring capability and containment of any released contamination
- ability to withstand static and dynamic loadings including tornado and seismic forces.

5.2.1.1 Alternative Vault Storage Concepts

Alternative storage concepts that use vaults involve variations in design and handling. Vaults could be designed to accommodate multiple canisters spaced in different arrays at various distances. The concept of individual sleeve storage and containment was selected for this report because it 1) provides secondary containment of contamination, 2) allows easy placement in storage without exposure to personnel, 3) allows retrieval of canisters, 4) isolates contamination from failed canisters, and 5) provides simple heat dissipation.

Two vault storage concepts based on the same basic storage module are described here. One concept provides for a 5- or 10-year storage capacity at the FRP site. The second concept provides larger storage capacities at an independent site. It is assumed that the larger facility would be a Federal interim storage repository.

5.2.1.2 Fuel Residue Vault Storage Facility Design Basis

Two capacities of the fuel residue vault storage facility (FRVSF) at the reference FRP are considered based on storage of canisters filled with uncompacted fuel assembly hardware and hulls, as well as canisters of failed equipment, generated during the first 5 years, or 10 years, of FRP operation. The FRP is assumed to operate at one-third capacity and two-thirds capacity during the first and second year of operation, respectively. The total number of standard-sized containers that can be stored at the 5-yr FRP facility is 2496 (both fuel residue and failed equipment canisters), including an allowance of about 13% excess capacity. Radioactivity contained in 2400 canisters of hulls and hardware at the end of the 5-yr accumulation period are listed in Table 5.2.2. Canisters filled with compacted residue or ingots, as described in Sections 4.2.2 and 4.2.3, could also be stored to accommodate correspondingly longer periods of FRP production. This vault storage facility is located near the FRP, and support facilities from the FRP are assumed to be available.

Two cases are considered for the FRVSF at an independent site. The capacity of one (Case A) is based on the cumulative number of fuel residue canisters (Section 4.2.1) and failed equipment canisters (Section 4.3.1) from all reprocessing operations through the year 1990, and the other (Case B) on the cumulative requirement through the year 1995. In 1990 the number of fuel residue canisters and failed equipment canisters is assumed to be 5620 and 835, respectively, and in 1995, 10800 and 1600, respectively. For Case A, the independent facility has a capacity of 6200 canisters, and for Case B, 11,900 canisters. These capacities represent a 5% excess over the required capacities.

TABLE 5.2.2. Radioactivity in FRP Fuel Residue Storage Facility[a] at the End of 5-yr Accumulation Period

	Total Inventory, Ci[b]
Fission Product Content,	
^{3}H	5.7×10^{5}
^{129}I	negligible
$^{90}Sr + {}^{90}Y$	6.0×10^{5}
$^{95}Zr + {}^{95}Nb$	2.3×10^{1}
$^{106}Ru + {}^{106}Rh$	4.7×10^{5}
$^{134}Cs + {}^{137}Cs + {}^{137m}Ba$	1.2×10^{6}
$^{144}Ce + {}^{144}Pr$	4.1×10^{5}
All other FPs	2.8×10^{5}
Total	3.5×10^{6}
Actinide Content,	
^{239}Pu	1.8×10^{3}
^{241}Pu	8.0×10^{5}
Other Pu	3.1×10^{4}
$Cm^{242} + Cm^{244}$	3.6×10^{4}
All other actinides	7.0×10^{3}
Total	8.8×10^{5}
Activation Products	
^{55}Fe	2.1×10^{7}
^{60}Co	3.1×10^{7}
$^{95}Zr + {}^{95}Nb$	1.0×10^{3}
All others	8.9×10^{4}
Total	5.2×10^{7}

a. Contained in 2400 canisters 76 cm dia by 3 m long
b. Based on waste characterization Table 3.3.28 for processing 10,000 MTHM, average of 3.5 years out of reactor, assuming uranium and plutonium recycle.

5.2.1.3 Fuel Residue Vault Storage Facility Operation

A storage sleeve in the FRVSF is prepared by removing the plug that covers the empty sleeve. A device to facilitate transfer of the hulls canister is then placed over the open sleeve. The device, called a hulls transfer device (HTD), consists of a collar that fits over a storage sleeve in the vault, and contains a two-piece sliding shielding gate. The gate opening is sized to permit passage of either a canister or a shielding plug. When a

transfer cask containing a hulls canister for storage arrives at the FRVSF, a crane picks it up and places it on top of the HTD already in position over the hole. Shielding gates on the transfer cask and on the HTD are opened, the canister is lowered into the storage location, and the gates are closed again. The cask is removed to a designated place away from the HTD, and the shielding plug is suspended from the crane on top of the HTD while the gates open and the plug is replaced in the sleeve. Retrieval of canisters from interim storage and transfer to a repository can be made by reversing this sequence of operations.

5.2.1.4 Fuel Residue Vault Storage Facility Description

This section presents general descriptions of the FRVSF at the FRP and at an independent site. Associated major equipment and shielding remain the same for the facility regardless of the site.

The FRVSF at the Reference FRP. Figure 5.2.1 is a plot plan of the FRVSF at the reference FRP. The facility is capable of functioning independently from the FRP. Its purpose is limited to providing storage and safeguards for the waste on a temporary basis. The operation and administration of the FRVSF takes place within the confines of its security fence; utilities, equipment maintenance, and personnel support facilities are, however, provided from the FRP.

The FRVSF comprises a modular arrangement of partially buried reinforced concrete structures called cells. The individual cells have roof slabs 1.2 m (4 ft) thick in which removable shielding plugs are built to allow storage and retrieval of residue. A 60-ton gantry crane is provided that services over one-half of the storage unit at a given time to handle the transfer cask, the hulls transfer device and the shielding plugs. Rails for the crane are provided for both halves of the storage unit. The vault is cooled by natural air circulation.

Figures 5.2.2 and 5.2.3 show plan and section views of a typical storage vault cell. The cell has two equal compartments, each with a capacity to store 156 canisters, for a total of 312 canisters per cell. Eight cells are provided to store 2496 canisters of residue from the FRP.

Each storage compartment has the floor slab sloped toward a longitudinal floor drain. The drain ends in a floor sump where any liquid from the vault is monitored before release to a retention pond located outside the vault. Runoff from the roof slab is directed through surface drains to the retention pond where, after monitoring, it is released to the site drainage system.

Several screened air intake structures are provided on each side of the vault to permit ambient air to enter the cell and circulate around the stored canisters. Hot air will leave through vents located at the center of the structure, where monitors are installed to detect any release of airborne contamination.

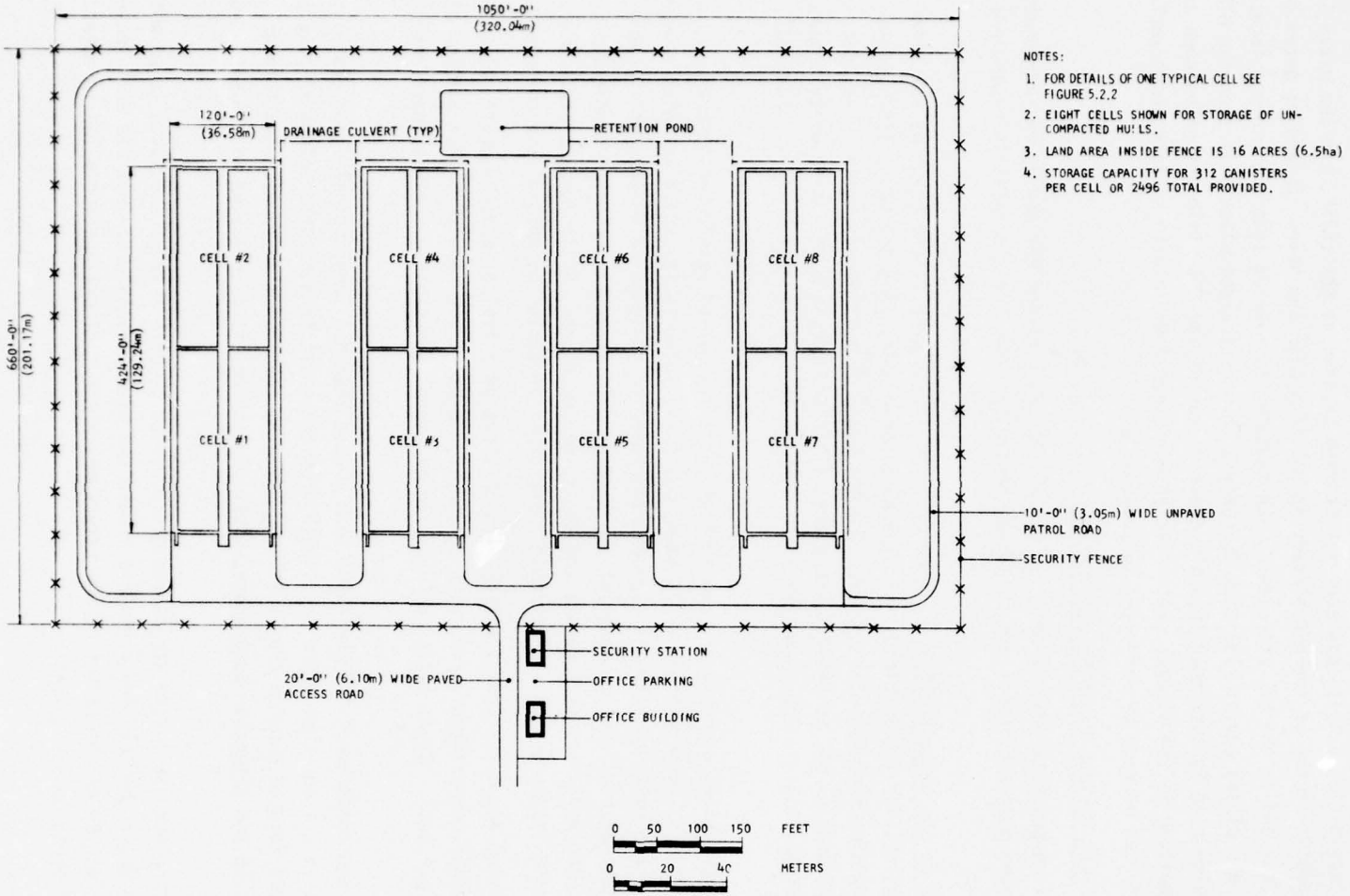
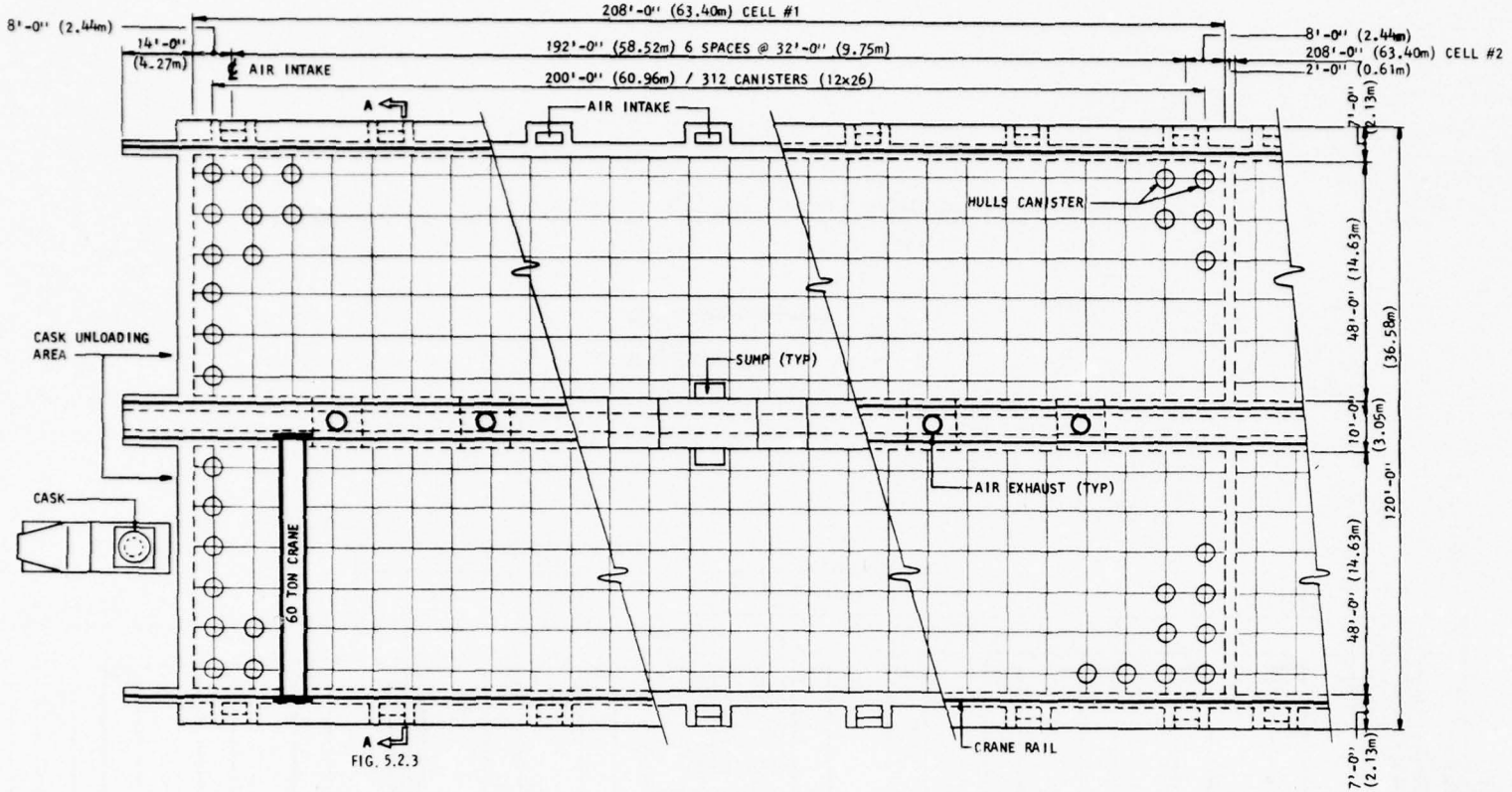


FIGURE 5.2.1. Fuel Residue Vault Storage Facility Plot Plan



NOTES:

1. ONE CELL SHOWN, EIGHT CELLS REQUIRED FOR UNCOMPACTED HULLS.

0 10 20 30 FEET

0 5 10 METERS

FIGURE 5.2.2. Fuel Residue Vault Storage Facility Storage Cell

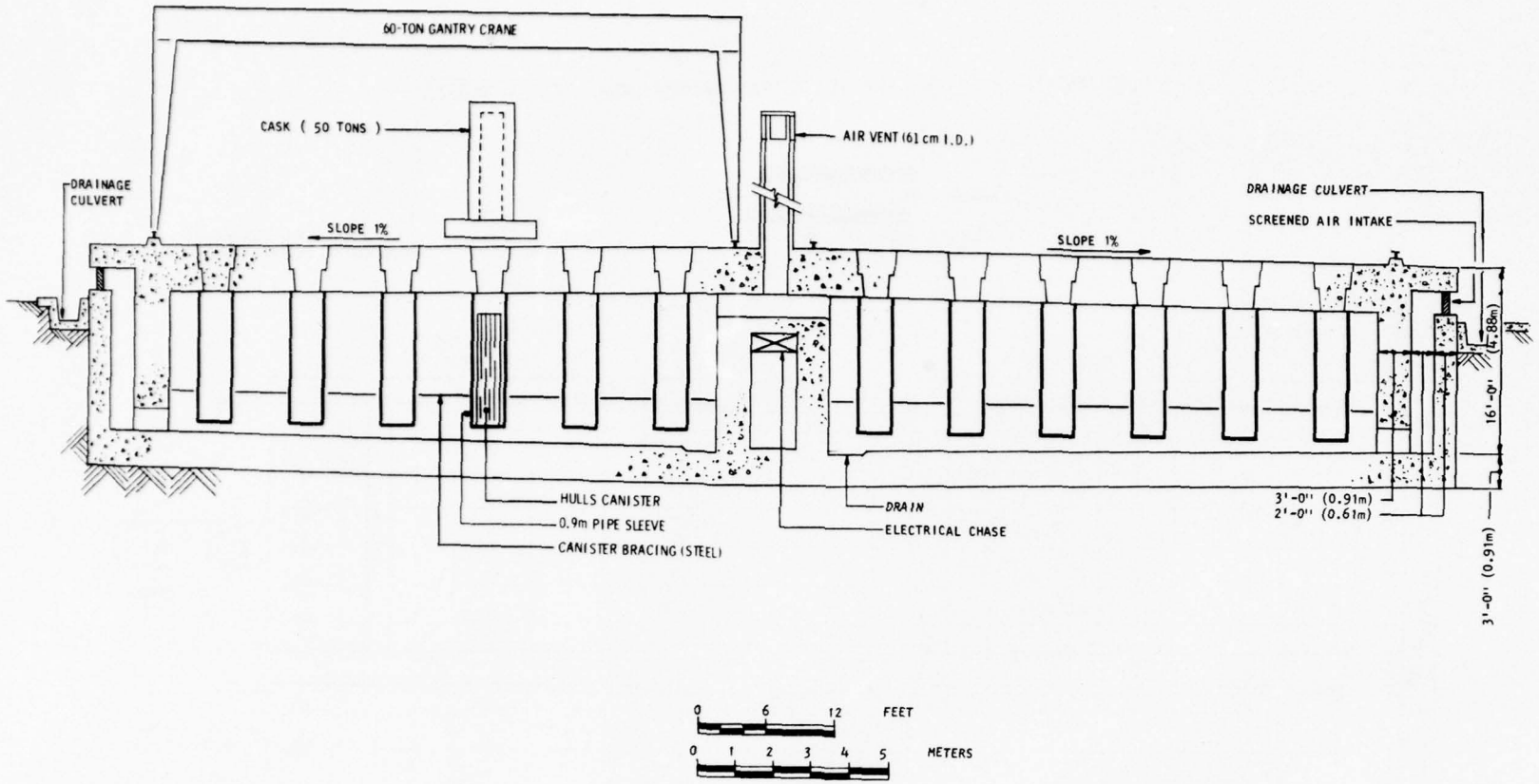


FIGURE 5.2.3. Fuel Residue Vault Storage Facility Storage Cell, Section A-A

Each storage space is a galvanized steel pipe sleeve with a plate welded to its bottom and suspended from the roof slab to supply the necessary containment for any material that may leak from the hulls container. In the event leakage occurs, the material will be held by this secondary container to prevent its escape. Closure at the shielding plug is made with neoprene gaskets to provide complete containment.

The FRVSF cells are Category I, uncoated, reinforced concrete structures, with galvanized carbon steel interior supports and sleeves for hulls containers.

General Description of the FRVSF at an Independent Site. The vault storage facility at an independent site comprises individual cells that are identical in construction to those described for storage at the FRP (see Figures 5.2.2 and 5.2.3). The independent site facility would periodically add more of these cells, or modules, to accommodate an increasing number of canisters of residue and failed equipment generated at the operating FRPs. The schedule for adding these modules is given in Section 5.2.1.10.

The FRVSF operates within the confines of the security fence provided for interim storage facilities at an independent site. Utilities, equipment maintenance, and personnel support facilities are shared with other interim storage operations.

Major Equipment Descriptions. The HTD, a 60-ton gantry crane, a transfer cask and a truck compose the major equipment requirements of the FRVSF at either site. Portable monitors are also used to detect contamination in the sump inside the vault by sampling through embedded pipes in the roof of the vault. Equipment requirements per cell for facilities at either the FRP or at an independent site are identical.

Shielding and Remote Handling Equipment. All canister handling is accomplished remotely with the gantry crane and HTD. Shielding of personnel from the gamma radiation in the stored hulls is provided by the roof slab 1.2 m (4 ft) thick. During transfer of the canister from the cask to the vault, personnel will be protected by the HTD. Additional shielding is provided by the soil surrounding the vault and by the concrete walls.

5.2.1.5 Fuel Residue Vault Storage Facility Operating and Maintenance Requirements

The required canister placements in storage can be done with a single 8-hr a day shift, 5 days a week. Two or three canisters would be placed in storage during each shift at the FRP site, yielding a yearly total of 551 canisters stored. At the independent site, storage requirements would reach about four canisters per shift (964 per year) in 1990 and about five canisters per shift (1331 per year) in 1995.

Staffing. The personnel required for FRVSFs at the FRP and at an independent site are listed in Table 5.2.3.

TABLE 5.2.3. Fuel Residue Vault Storage Facility Staffing Requirements

Job Description	Personnel Required, man-yr/yr	
	At FRP	At An Independent Site
Operators	1	2
Radiation monitors	0.5	1
Maintenance craftsmen	0.5	1

Supplies and Utilities. Estimated supplies and utilities needed for this task at the FRP and at an independent site are shown in Table 5.2.4.

TABLE 5.2.4. Fuel Residue Vault Storage Facility Supply and Utility Requirements

Supply or Utility	Use Rate	Annual Requirement	
		At FRP	At an Independent Site
Electricity	2,500 kW	5×10^6 kWh	10×10^6 kWh
Diesel fuel	5 ℓ/hr	7,600 ℓ	15,000 ℓ

Hazardous Materials. The packaged waste in storage is the only hazardous material.

5.2.1.6 Fuel Residue Vault Storage Facility Secondary Radioactive Wastes

No secondary wastes are expected from these storage operations during routine operations. Decontamination wastes would be produced in the event of an accident involving a canister breach.

5.2.1.7 Fuel Residue Vault Storage Facility Emissions

No radioactive effluents are expected from routine operation of this facility. The heat generation rate from a 1-yr accumulation of fuel residue is about 130 kW. A 5-yr accumulation at the FRP generates about 500 KW of heat. The waste accumulated at an independent site by 1990 and 1995 from all FRPs generates about 1,100 kW and 2,100 kW, respectively, of isotopic heat.

5.2.1.8 Fuel Residue Vault Storage Facility Decommissioning Considerations

The FRVSF is designed for retrieval of waste canisters during a 20-yr storage period. Essentially no contamination of the facility should result from interim storage of these wastes, thus making decommissioning a simple process.

5.2.1.9 Fuel Residue Vault Storage Facility Postulated Accidents

The FRVSF at the FRP and at an independent site is a static system except when canisters are being added or removed. Thus, any container breach accident will occur during loading or unloading operations. Table 5.2.5 describes a postulated moderate accident. Minor accidents

TABLE 5.2.5. Fuel Residue Vault Storage Facility Moderate Accidents

Accident No. and Description	Sequence of Events	Safety System	Release
5.2.1 – Waste hulls, canister breached by drop; expected frequency, ~0.2 per year.	1. Hulls canister dropped from crane. 2. Canister breached by fall. 3. Exposed material entrained. 4. Remote cleanup of spill.	1. Crane and lifting jig inspected prior to use. 2. Crane height limited to minimize impact force. 3. Sand matrix minimizes exposed material.	7×10^{-5} of one waste hulls canister released to atmosphere. See Table 5.2.1 for a description of this inventory.

would involve incidents where the canister is not breached and no radioactivity is released. No accidents that could be classified as severe accidents could be realistically postulated for this technology.

For purposes of environmental consequence analysis, the release from Accident 5.2.1 (waste hulls canister breached by drop) has been selected as an umbrella source term (see section 3.7 - Basis for Accident Analysis). This means the activity in this release is largest for those accidents in this source term category for the waste management system. (Source term categories are cross indexed by accident number in Appendix A of Section 3.) The source term for this accident was developed in Reference 4. It was assumed that 35% of the hulls escape the container and cask as a result of the drop and that 40% of the escape fraction was available for entrainment in the form of fines. A release coefficient of 5×10^{-4} was used for the available material, resulting in an overall release fraction of 7×10^{-5}.

Criticality safety in interim storage of fuel residue is ensured by the low residual UO_2 content of each canister and the low average concentration of fissile material in the hulls. The total undissolved fuel in the canister will be limited to a fraction of the minimum critical mass (Barnwell Nuclear Fuel Plant specifies 0.75). The critical mass depends on the enrichment of the fuel being processed. The minimum critical mass of a UO_2-H_2O water-reflecting sphere at 5% ^{235}U is 1.56 kg ^{235}U (31.2 kg total uranium). The minimum critical mass is higher for fuels of lower enrichment. Further, criticality is not possible unless the average uranium concentration is over 290 g of uranium per cm^3.

In practice, the uranium content in these fuel residues will be low because of the efficient dissolution process. Assuming that 0.1% of the spent fuel core remains with the hulls, the reference canister (Table 5.2.1) will contain 4 kg total uranium, far below the 31 kg minimum critical mass. A leached hull monitor, as well as administrative controls, will be used to ensure nearly-quantitative leaching of the fuel. For near surface or vault facilities neutron interaction between adjacent containers (i.e., neutrons originating in one container causing reactions in nearby containers) will be small but will be further limited by physical limitations on stacking geometry. The effects of plutonium content will also be factored into the criticality control procedures.

5.2.1.10 Fuel Residue Vault Storage Facility Costs

Estimates have been developed in mid-1976 dollars for capital, operating, and levelized unit costs for an FRVSF with a capacity to store 2496 canisters of fuel residue and of failed

equipment. Estimates for the larger independent site facility can be scaled from those given for this basic storage module. A complete description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Cost. Table 5.2.6 gives the capital cost estimate for constructing the FRVSF basic storage module. The estimate covers all capital costs specifically resulting from building the facility as a nearby adjunct to the FRP described in Section 3.2. These costs also include the effect of additions to utility supplies such as electrical substation; heating, ventilating, and air conditioning (HVAC); compressed air; and similar auxiliaries at the FRP; as well as the cable, piping, and other bulk materials incorporated directly into the FRVSF. However, general FRP costs for services such as laboratories and warehousing are not allocated to the FRVSF.

TABLE 5.2.6. Capital Cost Estimate for the Fuel Residue Vault Storage Facility Basic Storage Module

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment[a]		5	1,200	100	1,300
Buildings and structures		2,615	18,700	31,400	50,100
Bulk materials		100	1,000	1,300	2,300
Site improvements		30	200	400	600
Subtotal of direct site construction costs		2,750	21,100	33,200	54,300
Indirect site construction costs	700	550	12,200	16,000	28,200
Total field cost	700	3,300	33,300	49,200	82,500
Architect-engineer services					14,500
Subtotal					97,000
Owner's cost					23,000
Total facility cost					120,000
Estimated accuracy range					±20%

a. Includes cask and truck for the transportation of hulls from the FRP to the FRVSF.

Table 5.2.7 shows the incremental capital costs for constructing support services facilities for the FRVSF at an independent site.

The FRVSF at an independent site provides storage capacity as required by waste generation from all FRPs through the year 1990 (Case A) and through the year 1995 (Case B). Storage capacity is assumed to be installed in increments of the basic module as shown, along with capital investment, in Table 5.2.8 for Case A and in Table 5.2.9 for Case B. The incremental cost for expansion modules is slightly less than the cost of the first module since certain equipment (such as the gantry crane and hulls transfer device) obtained at the time of initial

TABLE 5.2.5. Incremental Capital Cost Estimate for the Independent Fuel Residue Vault Storage Facility Support Services[a]

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		3	300		300
Buildings and structures					
Bulk materials					
Site improvements		20	100	200	300
Subtotal of direct site construction costs		23	400	200	600
Indirect site construction costs	3	11	100	100	200
Total field cost	3	34	500	300	800
Architect-engineer services					100
Subtotal					900
Owner's cost					200
Total facility cost					1100
Estimated accuracy range					±25%

a. These cost differentials result from building this facility as an independent, self-supporting storage site rather than as part of the FRP.

TABLE 5.2.6. Capital Investment Schedule for a Case A Fuel Residue Vault Storage Facility at an Independent Site

Year	Capacity Increase, Number of Canisters	Capital Cost, 10^6 Dollars
1981	2496	121
1986	3959	171
Total	6455	292

TABLE 5.2.9. Capital Investment Schedule for a Case B Fuel Residue Vault Storage Facility at an Independent Site

Year	Capacity Increase, Number of Canisters	Capital Cost, 10^6 Dollars
1981	2,496	121
1986	2,496	118
1989	2,496	118
1991	2,496	118
1994	2,416	115
Total	12,400	590

module construction can be used throughout the facility. If a module size other than the basic size (2496 canister capacity) is required, the basic module cost (Table 5.2.6) is scaled using a 0.8 exponent factor. The costs shown in Tables 5.2.8 and 5.2.9 incorporate the costs listed in Table 5.2.7, and as such encompass all capital expenses resulting from constructing the FRVSF at an independent site, including the cost of providing the utilities and services required for its normal operation and support.

Figures reflecting total capital costs include all plant-related costs from the start of engineering to the initiation of commercial operation, with the exception of working capital.

Operating Cost. The annual operating costs for vault storage at the FRP are shown in Table 5.2.10. The operating costs for vault storage at an independent site are shown in Table 5.2.11. These tables reflect costs for two operational modes--filling the fault and surveillance during dead storage. For vault filling, estimates of operating labor and utilities are based on requirements shown in Tables 5.2.3 and 5.2.4. Annual maintenance materials costs are estimated at 2% of the initial equipment investment. The estimates for the miscellaneous items include all unidentified operating costs. For storage surveillance, direct labor is estimated at one man-year; maintenance is one-half annual maintenance during loading, and overhead is calculated on direct labor as outlined in Section 3.8.2. Utility requirements are assumed to remain the same as during filling operations.

TABLE 5.2.10. Operating Cost Estimate for the Fuel Residue Vault Storage Facility at the FRP

Cost Element	Annual Costs, $1000s			
	Filling Mode		Storage Mode	
Direct labor	30		16	
Process materials	0		0	
Utilities	100		100	
Maintenance materials	30		13	
Overhead	50		25	
Miscellaneous	370		0	
Total	580	+50% -25%	154	+50% -25%

Levelized Unit Costs. Levelized unit costs for two scenarios are shown in Table 5.2.12 for facilities at the FRP. The first scenario assumes:

- The FRP-generated wastes will be stored onsite for 5 years.
- The cumulative waste volume amounts to approximately 2200 canisters.
- The canisters are stored in a standard 2496-canister facility.

The second scenario assumes:

- Wastes will be stored onsite for 10 years.
- The cumulative waste volume is approximately 5000 canisters.
- The canisters are stored in one 2490-canister and one 2700-canister facility.

TABLE 5.2.11. Operating Cost Estimate for the Fuel Residue Vault Storage Facility at an Independent Site (Operating cost is the same for Cases A and B.)

Cost Element	Annual Costs, $1000s Filling Mode		Storage Mode	
Direct labor	60		16	
Process materials	0		0	
Utilities	200		200	
Maintenance	30		16	
Overhead	90		25	
Miscellaneous	370		0	
Total	750	+50% -25%	257	+50% -25%

TABLE 5.2.12. Levelized Unit Cost Estimate for the Fuel Residue Vault Storage Facility at the FRP

Cost Element	Unit Cost, $/kgHM 5-yr storage	10-yr storage
Levelized capital charge	34.50	32.60
Levelized operating charge	0.90	0.60
Levelized total unit cost	35.40 ±25%	33.20 ±25%

...RP-related scenarios assume:

- Storage facilities are privately owned.
- There is a 10-yr period following storage to transfer the waste to a Federal repository.
- The unit operating costs for transferring wastes are the same as those for loading the facility.

A comparison of the unit cost estimates for the two scenarios indicates that most of the cost is associated with placing the waste into storage. The additional cost of dead storage for holding the waste is very small.

Levelized unit costs for storage of waste at an independent site are shown in Table 5.2.13 for Case A (storage of canisters produced through 1990) and Case B (storage of canisters produced through 1995). Transfer of the waste to a Federal repository is then assumed to be accomplished over a 10-yr period. Operating costs during surveillance storage are calculated on the same basis as explained for FRP storage. All waste is assumed to be transferred from one facility before the next facility begins transfer. Unit operating costs for transferring waste out of the facility are assumed to be the same as unit operating costs for loading the facility. Both cases assume government ownership of the independent facilities.

As with FRP site storage, the storage period at the independent site has little impact on unit storage cost. The lower unit cost at the independent site reflects lower capital charges due to lower cost of capital and elimination of income tax costs.

TABLE 5.2.13. Levelized Unit Cost Estimates for the Fuel Residue Vault Storage Facility at an Independent Site

Cost Element	Unit Cost, $/kgHM	
	Case A (1990)	Case B (1995)
Levelized capital charge	16.70	16.90
Levelized operating charge	0.60	0.50
Levelized total unit cost	17.30 ±25%	17.40 ±25%

5.2.1.11 Fuel Residue Vault Storage Facility Construction Requirements

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the impact of construction activities. This information has been developed for an FRVSF with a capacity to store 2496 canisters and located within the general property area of the FRP. Similar data for the larger independent site facility can be obtained by linear scaling.

Project Schedules and Construction Manpower. The estimated schedule for engineering, procurement, and construction of the FRVSF is shown in Figure 5.2.4. The construction labor force size, composition, and schedule is shown in Figure 5.2.5.

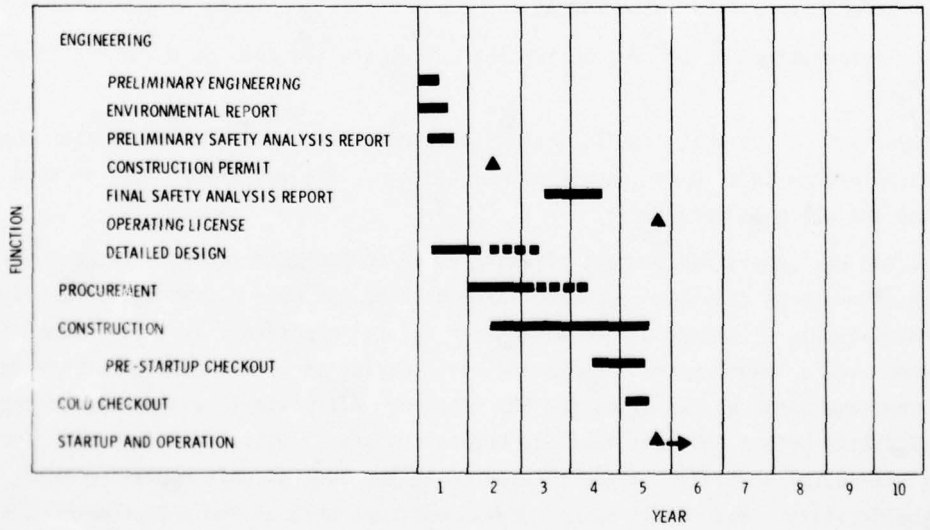


FIGURE 5.2.4. Engineering, Procurement, and Construction Schedule for the Fuel Residue Vault Storage Facility

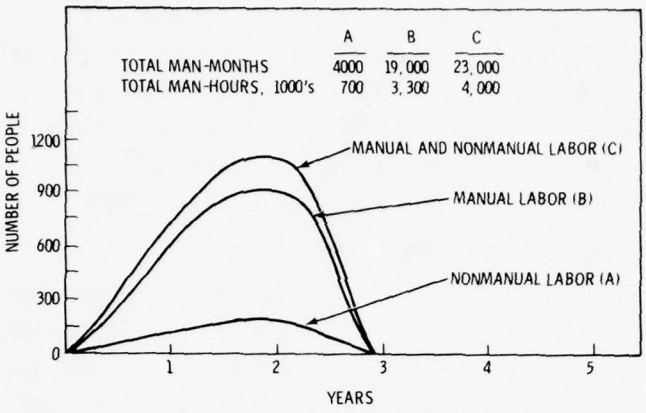


FIGURE 5.2.5. Contruction Labor Force Schedule for Fuel Residue Vault Storage

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site; offsite costs are those for all services provided, equipment fabricated or assembled, and materials purchased elsewhere. The distribution of total costs in these categories is as follows:

	Costs, $1000s
Onsite	52,000
Offsite	68,000
Total	120,000

Construction Facilities and Materials. Temporary construction facilities include field offices; construction warehouse and tool room; craft shops for piping, electrical instrumentation, etc.; construction parking areas; and construction storage areas.

Site Requirements. The FRVSF at the FRP requires 8 ha (20 acres) within the FRP site. An additional 2 ha (5 acres) are required for construction storage, work yards, temporary buildings and labor parking. The independent facility is located on a 160-ha (400-acre) site. About 14 ha (34 acres) and 26 ha (65 acres) are required for vault storage in 1990 and 1995, respectively. An additional 2 ha (5 acres) are needed for contruction storage, work yards, temporary buildings and labor parking.

Water. About 60,000 m^3 (16 x 10^6 gal) of water are required during the construction period.

Construction Materials. Materials committed to facility construction are:

Concrete	59,000 m^3	(77,000 yd^3)
Steel	14,500 MT	(16,000 short tons)
Copper	9 MT	(10 short tons)
Lead	45 MT	(50 short tons)
Aluminum	negligible	negligible
Lumber	3,140 m^3	(1,330 MFBM)

Energy. Energy resources used during construction are:

Propane	450 m^3	(120,000 gal)
Diesel fuel	4,500 m^3	(1,200,000 gal)
Gasoline	3,000 m^3	(800,000 gal)
Electricity		
Peak demand	1,250 kW	
Total consumption	2,280,000 kWh	

Transportation Requirements. A short road is required between the FRP and the FRVSF facility. This road must be designed for trucks hauling the hulls cask. For the independent facility, approximately 1.6 km (1 mile) of 2-lane paved road will be required to the nearest U.S. highway.

5.2.1.12 Effects of Fuel Cycle Options

The FRVSF is based on reprocessing of LWR fuel and recycling the recovered uranium and plutonium. Requirements for other fuel cycle options are discussed in this section.

No Recycle. No storage facility is required for the fuel cycle option.

Uranium Recycle Only, with Plutonium to a Repository. Storage facilities for this fuel cycle option and the basis option are identical.

Uranium Recycle Only, with Plutonium to HLW. Storage facilities for this option and the basis option are identical.

5.2.2 Subsurface Storage of Fuel Residue

Caisson berm storage is an alternative method for interim storage of fuel residue.[3] This type of storage is similar to the vault storage concept except the facility is an engineered, above-grade soil structure. The canisters are placed in caissons positioned vertically in the soil structure or berm. The caissons are capped with a steel and concrete plug.

5.2.2.1 Alternative Subsurface Storage Concepts

Alternative concepts for subsurface storage of fuel residue involve variations in design and handling. The concept selected for this report was chosen on the basis of:

1) ease of canister placement with minimum exposure of personnel, 2) excellent secondary containment, 3) ease of canister retrievability, 4) isolation of contamination from a failed canister, and 5) simple heat dissipation.

As with the vault storage discussion, two subsurface storage concepts based on one basic storage module is described here. One concept provides storage capacity at the FRP site for the first five years of operation. The second concept provides for larger storage capacities at an independent site. This larger facility is assumed to be a Federal interim storage repository.

5.2.2.2 Fuel Residue Subsurface Storage Facility Design Basis

The bases for the designs of the facilities at the FRP and at an independent site are the same as those given for vault storage in Section 5.2.1.2.

5.2.2.3 Fuel Residue Subsurface Storage Facility Operation

Storage operations at the fuel residue subsurface storage facility (FRSSF) are the same as those outlined in Section 5.2.1.3 for the FRVSF.

5.2.2.4 Fuel Residue Subsurface Storage Facility Description

The FRSSF is designed to be operated either as an adjunct to the FRP described in Section 3.2 or as an independent facility.

General Description of FRSSF at the Reference FRP. The FRSSF is capable of functioning independently from the FRP. Its purpose is limited to providing storage and safeguards for the waste on a temporary basis. This facility is operated and maintained from within the confines of the FRSSF security fence; however, utilities, equipment maintenance, and personnel support facilities are provided from the FRP.

Figure 5.2.6 is a plot plan of the FRSSF at the FRP. The facility consists of two, parallel above-grade berms constructed from suitable soils materials; residue containers are stored in individual steel caissons within the berms. The individual storage positions have removable shielding plugs 1.2 m (4 ft) thick to allow for storage and retrieval of containers through a special-purpose hulls transfer device (HTD). A 60-ton gantry crane runs over one-half of the berm and handles the hulls cask, the HTD, and the shielding plugs. Cooling of the berms is achieved by conduction through the soils.

Figures 5.2.7 and 5.2.8 show plan and section views of a typical individual storage berm. The berm has two equal sections, each with a capacity to store 624 canisters, or a total of 1248 canisters per berm. Runoff from the berm, as well as internal drainage, will be directed to the peripheral drains and to the retention pond for release to the site drainage system after monitoring.

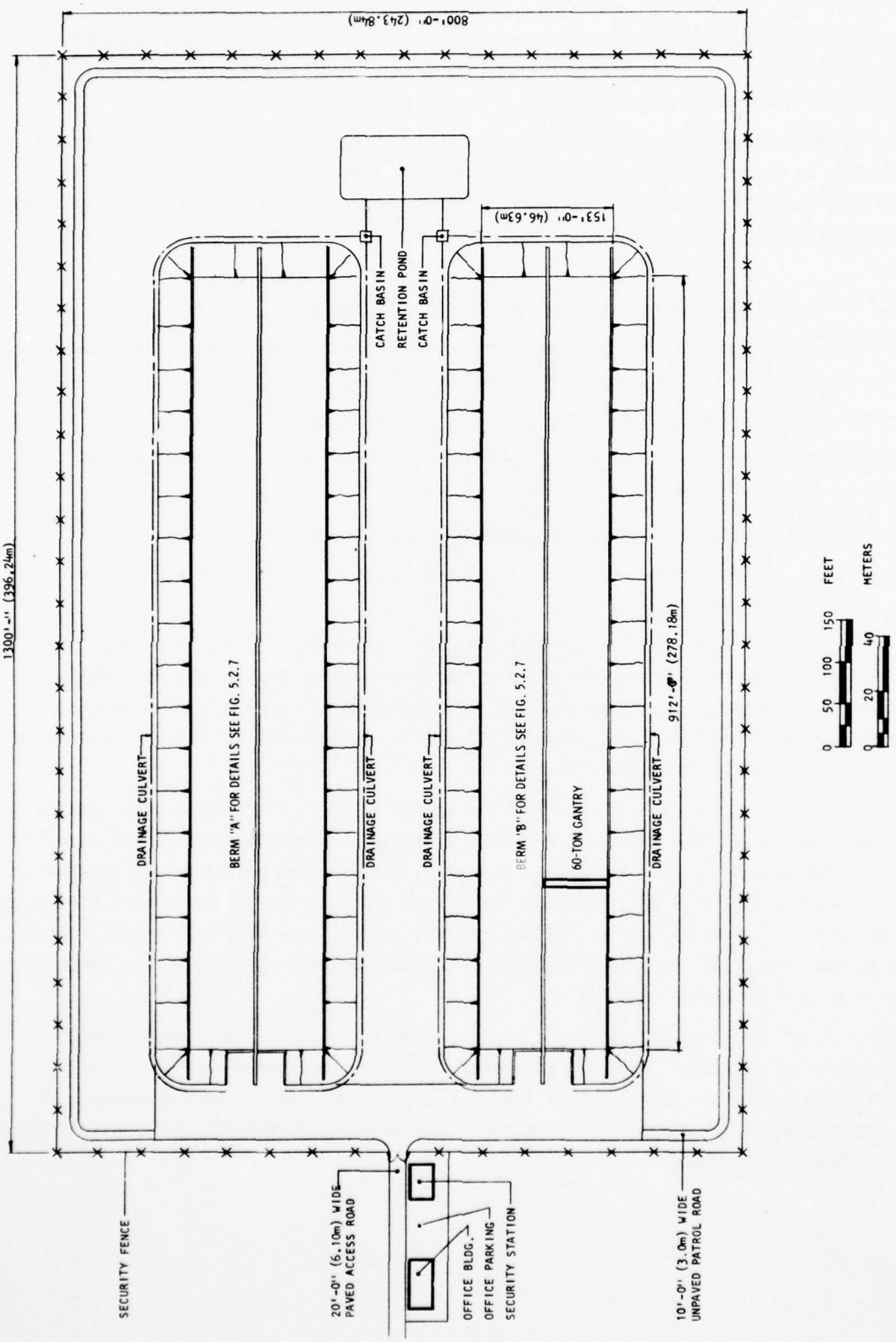


FIGURE 5.2.6. Fuel Residue Subsurface Storage Facility Plot Plan

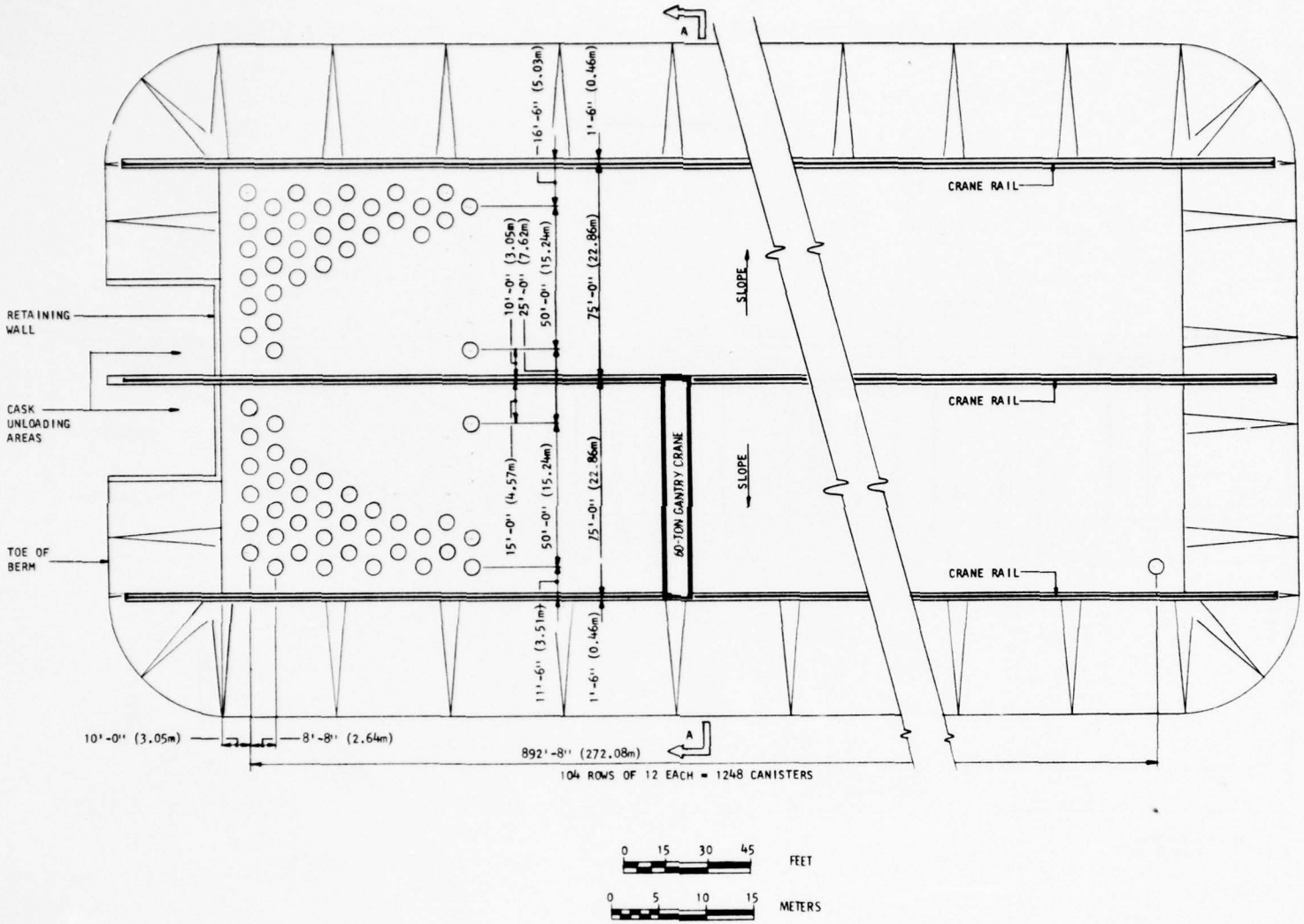


FIGURE 5.2.7. Storage Berm Plan for the Fuel Residue Subsurface Storage Facility

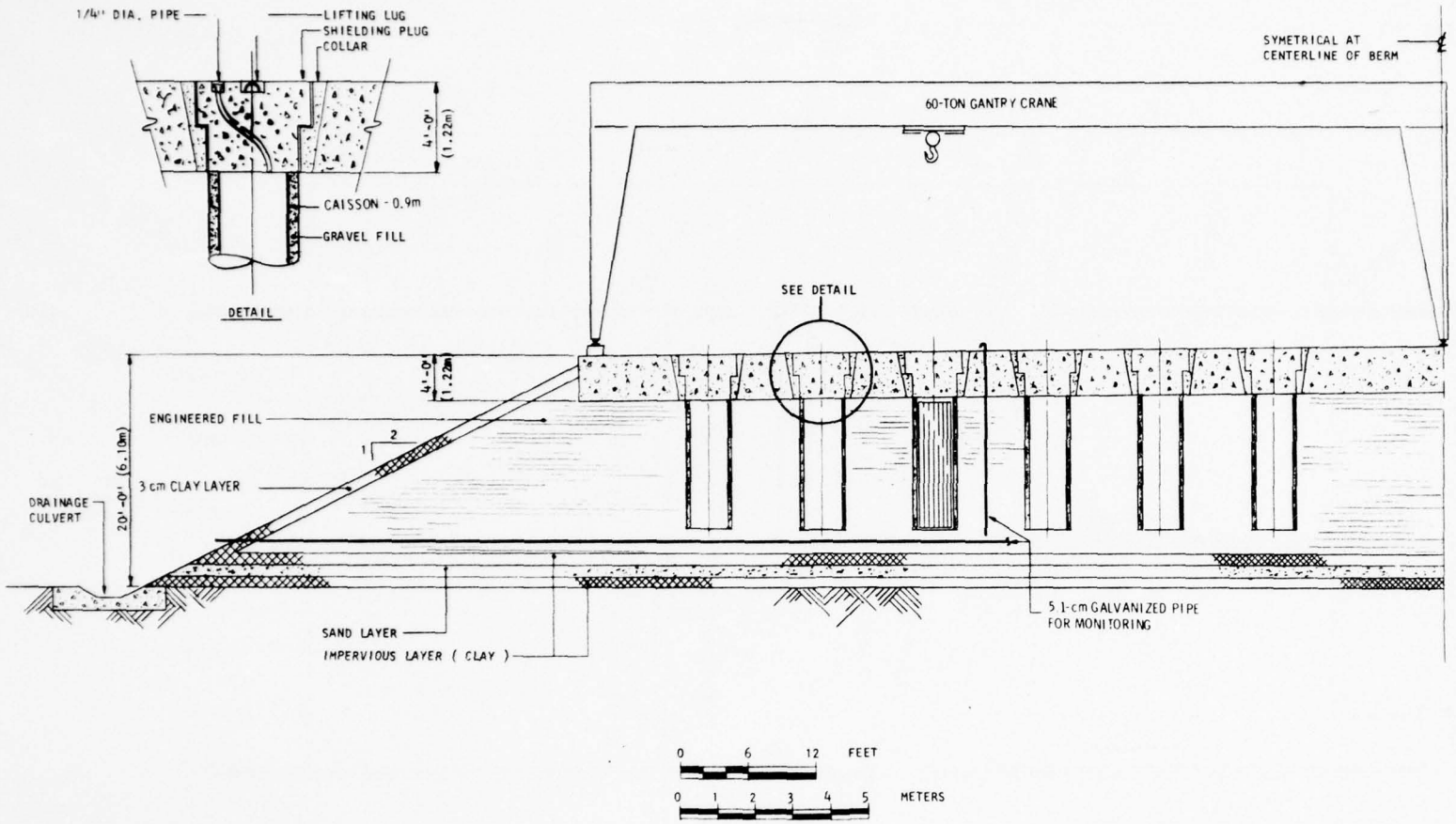


FIGURE 5.2.8. Storage Berm for the Fuel Residue Subsurface Storage Facility, Section A-A

The berm is compacted to 95% of its maximum dry density, as measured by the modified American Association of State Highway and Transportation Officials tests. Galvanized steel caissons are placed on 1.1-m (42 in.) drilled holes, and granular material is filled between the berm and the caissons to isolate the caissons from the adjacent fill material. Shielding plugs with matching collars are installed and centered on each caisson, and a concrete slab 1.2 m (4 ft) thick is poured on top of the berm.

Each storage space consists of a galvanized steel pipe sleeve 0.9 m (3 ft) in diameter, with a plate welded to its bottom and suspended from the slab to supply the necessary containment for any material that may leak from the stored canister. Gravel is backfilled around the outside of the pipe. In the event leakage occurs, the leaking material will be held by this secondary container and will not escape. Closure at the shielding plug is made with neoprene gaskets to provide complete containment.

General Description of the FRSSF at an Independent Site. The FRSSF at an independent site consists of parallel, above-grade berms constructed identically to those provided at the FRP. Berm storage capacity will be added as required to accommodate wastes generated from all FRPs through 1990 (Case A) and through 1995 (Case B). The schedule for capacity expansion is given in Section 5.2.2.10. Utilities, equipment maintenance, and personnel support facilities are provided at the independent site for residue and failed equipment canister storage and for other waste storage containers. Operation and maintenance of this facility is made from within the confines of the FRSSF security fence.

Major Equipment Descriptions. The HTD, a 60-ton gantry crane, a transfer cask and a truck are the major equipment items for the FRSSF at either site. Portable beta-gamma monitors are used to detect any leakage of activity from the canister into the secondary container by drawing an air sample through a probe installed through the shielding plug into the storage caisson. Portable monitors are also used to detect any contamination inside the berm through sampling probes installed in the berm. Radiation monitor tubes are installed on the shielding plugs, in the berm top, and on the side slopes to provide for periodic testing for contamination. Equipment requirements for each berm are identical for facilities at either an independent site or at the FRP.

Shielding and Remote Handling Equipment. All canister handling is accomplished remotely with the gantry crane and HTD. Shielding of personnel from the gamma radiation in the stored residue is provided by a concrete slab 1.2 m (4 ft) thick. During the transfer of the canister from the cask to the vault, personnel will be protected by the HTD. Additional shielding is provided by the soil surrounding the berm.

5.2.2.5 Fuel Residue Subsurface Storage Facility Operating and Maintenance Requirements

Operating and maintenance requirements are identical to those presented in Section 5.2.1.5.

5.2.2.6 Fuel Residue Subsurface Storage Facility Secondary Radioactive Wastes

No secondary radioactive wastes from routine operations are expected for the reference facilities. Decontamination wastes would be produced in the event of an accident involving a canister breach.

5.2.2.7 Fuel Residue Subsurface Storage Facility Emissions

No radioactive effluents are expected from routine operation of this facility. The isotopic heat generation from a 1-yr accumulation of fuel assembly residue at the FRP is about 130 kW. A 5-yr accumulation at the FRP generates about 500 kW of heat. The waste accumulated at an independent site by 1990 and 1995 generates about 1,100 kW and 2,160 kW, respectively, of isotopic heat.

5.2.2.8 Fuel Residue Subsurface Storage Facility Decommissioning Considerations

Information for this section is identical to that presented in Section 5.2.1.8.

5.2.2.9 Fuel Residue Subsurface Storage Facility Postulated Accidents

Information for this section is identical to that presented in Section 5.2.1.9.

5.2.2.10 Fuel Residue Subsurface Storage Facility Costs

Estimates have been developed in mid-1976 dollars for capital, operating, and levelized unit costs. A complete description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Cost. Table 5.2.14 shows the capital cost estimate for the FRSSF facility at the FRP. This facility represents the basic storage module, with a capacity of 2496 canisters. The estimate covers all capital costs specifically resulting from building the facility as a nearby adjunct to the FRP described in Section 3.2. These costs also include the effect of incremental additions to utility supplies such as electrical substation, HVAC, and compressed air, as well as the cable, piping, and other bulk materials incorporated directly into the FRSSF. However, general FRP costs for services such as laboratories or warehousing have not been allocated to the FRSSF.

The FRSSF at an independent site provides storage capacity as required by waste generation from all FRPs through the year 1990 (Case A) and through the year 1995 (Case B). Storage capacity is assumed to be installed in increments of the basic module as shown, along with capital investment, in Table 5.2.15 for Case A and in Table 5.2.16 for Case B. The incremental cost for expansion modules is slightly less than the cost of the first module since certain equipment (such as the gantry crane and hulls transfer device) obtained at the time of initial module construction can be used throughout the facility. If a module size other than the basic size (2496 canister capacity) is required, the basic module cost (Table 5.2.14) is scaled using a 0.8 exponent factor. The costs shown in Tables 5.2.15 and 5.2.16 encompass all capital expenses resulting from constructing the FRSSF at an independent site, including the cost of providing the utilities and services required for its normal operation and support (see Table 5.2.7).

Figures reflecting total capital costs include all plant-related costs incurred from the start of engineering to the initiation of commercial operation with the exception of working capital.

TABLE 5.2.14. Capital Cost Estimate for the Fuel Residue Subsurface Storage Facility Basic Storage Module

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment[a]		5	1,200	100	1,300
Buildings and structures		510	6,700	6,200	12,900
Bulk materials		105	1,000	1,300	2,300
Site improvments		80	400	900	1,300
Subtotal of direct site construction costs		700	9,300	8,500	17,800
Indirect site construction costs	190	140	3,200	4,000	7,200
Total field cost	190	840	12,500	12,500	25,000
Architect-engineer services					4,000
Subtotal					29,000
Owner's cost					6,000
Total facility cost					35,000
Estimated accuracy range					±20%

a. Includes cask and truck for the transportation of canisters from the FRP to the FRSSF.

TABLE 5.2.15. Capital Investment Schedule for a Case A Fuel Residue Subsurface Storage Facility at an Independent Site

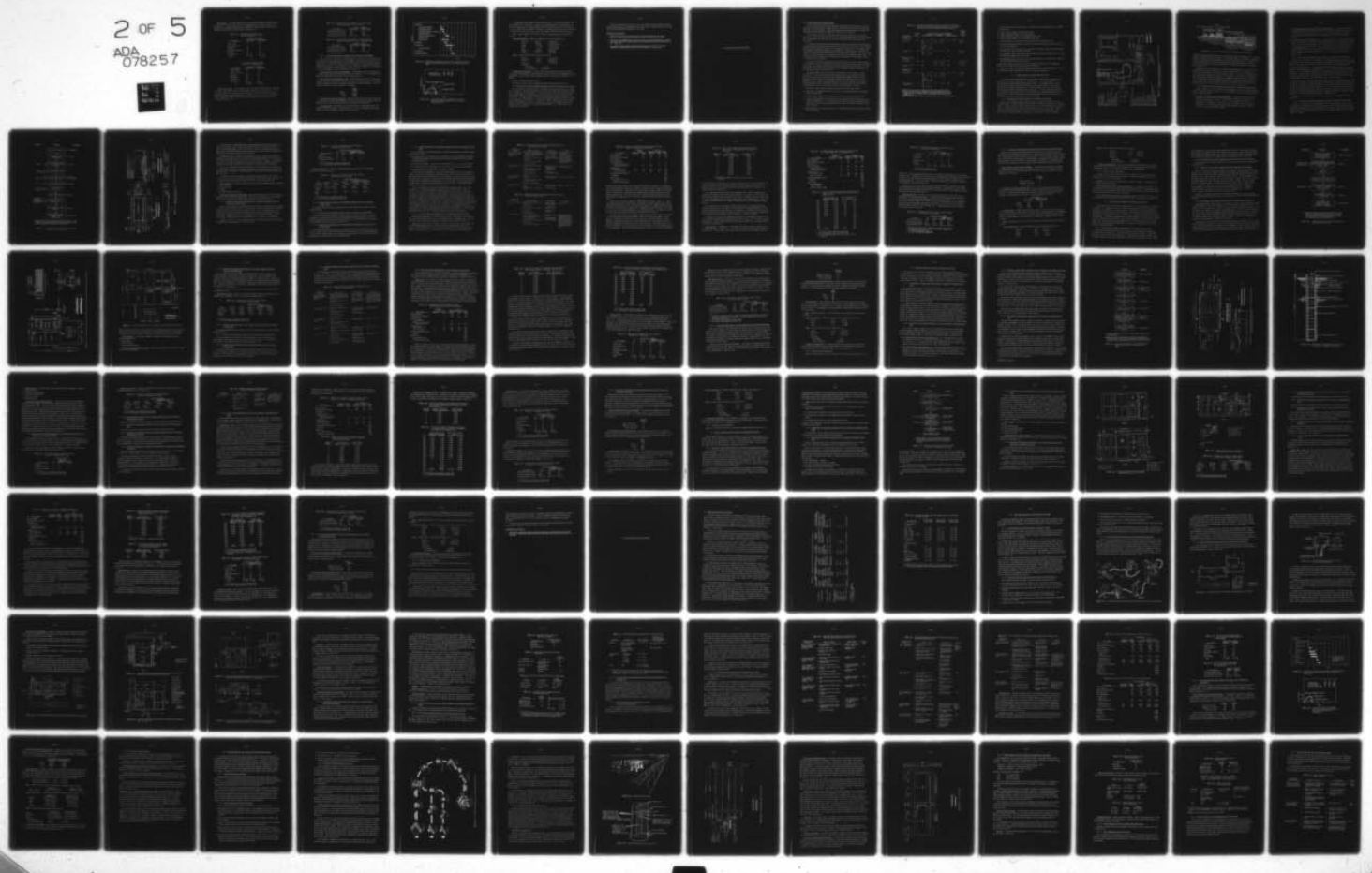
Year	Capacity Increase, Number of Canisters	Capital Cost, 10^6 Dollars
1981	2496	36
1986	3959	51
Total	6455	87

TABLE 5.2.16. Capital Investment Schedule for a Case B Fuel Residue Subsurface Storage Facility at an Independent Site

Year	Capacity Increase, Number of Canisters	Capital Cost, 10^6 Dollars
1981	2,496	36
1986	2,496	33
1989	2,496	33
1991	2,496	33
1994	2,416	32
Total	12,400	167

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Operating Cost. The annual operating costs for subsurface storage at the FRP are shown in Table 5.2.17. The costs for storage at an independent site are shown in Table 5.2.18. Operating costs have been developed for both loading and surveillance modes using the same assumptions as outlined for vault storage in Section 5.2.1.10.

TABLE 5.2.17. Operating Cost Estimate for the Fuel Residue Subsurface Storage Facility at the FRP

Cost Element	Annual Costs, $1000s Filling Mode		Storage Mode	
Direct labor	30		16	
Process materials	0		0	
Utilities	100		100	
Maintenance materials	30		13	
Overhead	50		25	
Miscellaneous	110		0	
Total	320	+50% -25%	154	+50% -25%

Fuel Residue Subsurface Storage Facility at an Independent Site

Cost Element	Annual Costs, $1000s Filling Mode		Storage Mode	
Direct labor	60		16	
Process materials	0		0	
Utilities	200		200	
Maintenance	30		16	
Overhead	90		25	
Miscellaneous	110		0	
Total	490	+50% -25%	257	+50% -25%

Levelized Unit Costs. The levelized unit costs are shown in Table 5.2.19 for the FRSSF at the FRP. Costs for the FRSSF at an independent site are shown in Table 5.2.20. The unit cost calculation assumes private ownership of the facilities at the FRP site and Federal government ownership at the independent site. Scenarios for the 5-yr and 10-yr FRP storage and for independent storage of canisters produced through 1990 and 1995 are the same as explained in Section 5.2.1.10.

TABLE 5.2.19. Levelized Unit Cost Estimate for the Fuel Residue Subsurface Storage Facility at the FRP

Cost Element	Unit Cost, $/kgHM 5-yr Storage	10-yr Storage
Levelized capital charge	10.00	9.40
Levelized operating charge	0.50	0.40
Levelized total unit cost	10.50 ± 25%	9.80 ± 25%

TABLE 5.2.20. Levelized Unit Cost Estimate for the Fuel Residue Subsurface Storage Facility at an Independent Site

Cost Element	Unit Cost, $/kgHM Case A (1990)	Case B (1995)
Levelized capital charge	5.00	4.80
Levelized operating charge	0.40	0.50
Levelized total unit cost	5.40 ± 20%	5.30 ± 20%

5.2.2.11 Fuel Residue Subsurface Storage Facility Construction Requirements

Many of the factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information which follows provides a basis for evaluating the impact of construction activities. This information is for an FRSSF with a capacity of 2496 canisters located within the general property area of the FRP. Materials requirements for larger facilities at an independent site can be obtained by linear scaling.

Project Schedules and Construction Manpower. The estimated schedule for engineering, procurement, and construction of the FRSSF is shown in Figure 5.2.9. The construction labor force size, composition, and schedule is shown in Figure 5.2.10.

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site, while offsite costs are those for all services provided, equipment fabricated or assembled, and materials purchased elsewhere. The distribution of total costs in these categories is as follows:

	Costs, $1000s
Onsite	13,000
Offsite	22,000
Total	35,000

Construction Facilities and Materials. Temporary construction facilities include temporary field offices; construction warehouse and tool room; craft shops for piping, electrical, mechanical, etc.; construction parking areas; and construction storage areas.

Site Requirements. Approximately 12 ha (29 acres) within the FRP property must be cleared for FRSSF installations. An additional 2 ha (5 acres) are needed for construction storage, work yards, temporary buildings, and labor parking.

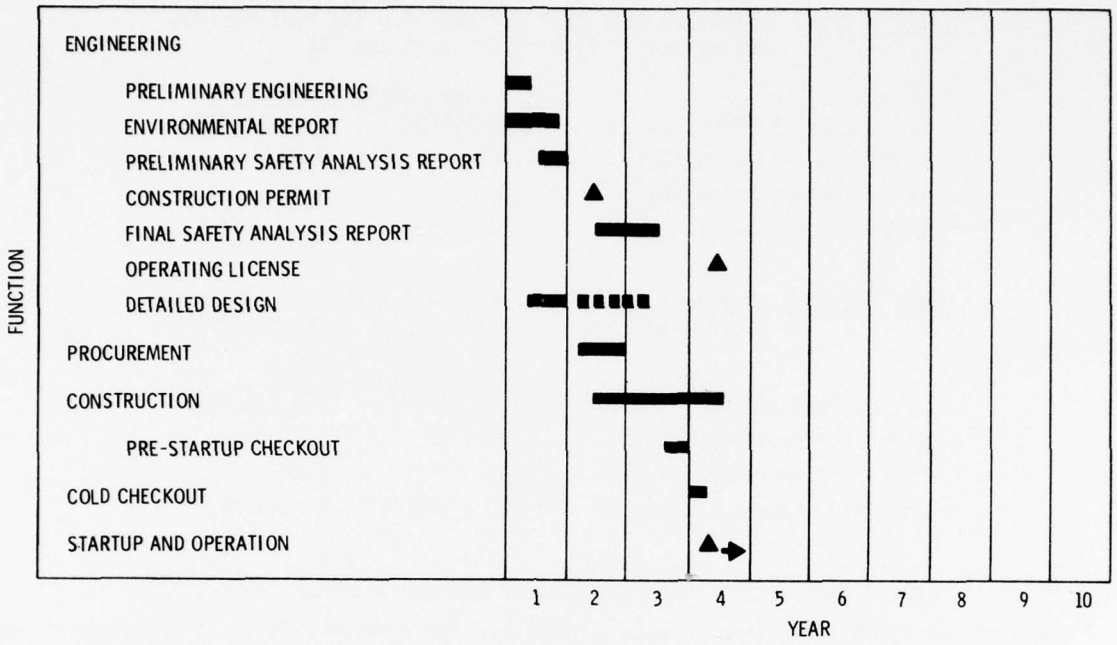


FIGURE 5.2.9. Engineering, Procurement, and Construction Schedule of the Fuel Residue Subsurface Storage Facility at the Fuel Reprocessing Plant

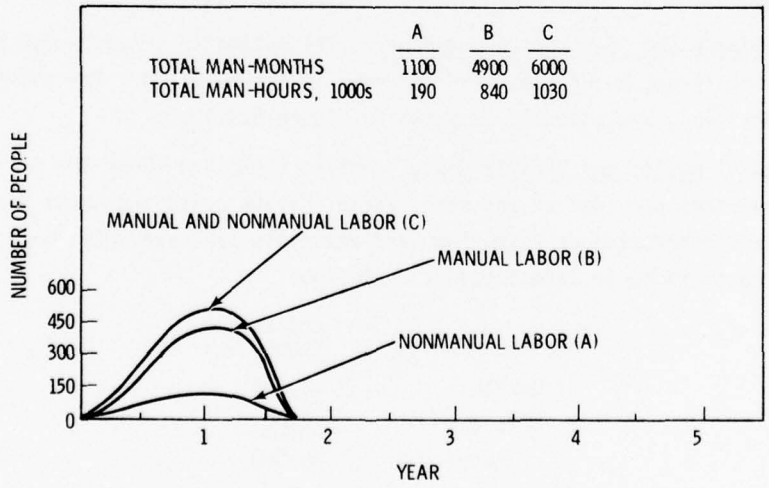


FIGURE 5.2.10. Construction Labor Force Schedule for the Fuel Residue Subsurface Storage Facility at the Fuel Reprocessing Plant

The independent FRSSF requires a 160-ha (400-acre) site. This site should be near the final disposal site if possible to reduce costs for transportation to final isolation. The facilities themselves will require an area of about 24 ha (60 acres) and 47 ha (115 acres) for Case A (1990) and Case B (1995), respectively. An additional area of about 2 ha (5 acres) is required for construction storage, work yards, temporary buildings, and labor parking.

Water. About 15,000 m^3 (4 x 10^6 gal) of water are required during the construction period.

Construction Materials. Materials committed to facility construction are:

Concrete	16,800 m^3	(22,000 yd^3)
Steel	3,600 MT	(4,000 short tons)
Copper	4.5 MT	(5 short tons)
Lead	45 MT	(50 short tons)
Aluminum	negligible	negligible
Lumber	1,040 m^3	(440 MFBM)

Energy. Energy resources used during construction are:

Propane	114 m^3	(30,000 gal)
Diesel fuel	1,170 m^3	(310,000 gal)
Gasoline	795 m^3	(210,000 gal)
Electricity		
Peak demand	570 kW	
Total consumption	590,000 kWh	

Transportation Requirements. A short road is required between the FRP and the FRSSF. This road must be designed for trucks hauling the transfer cask. For the independent facility, approximately 1.6 km (1 mile) of two-lane paved road will be required to the nearest U.S. highway.

5.2.2.12 Effects of Fuel Cycle Options

Information for this section is identical to that presented in Section 5.2.1.12.

5.2.3 Physical Protection and Safeguard Requirements for Interim Storage of Fuel Residue

The fuel residue in interim storage in an unattractive and unavailable target for either theft or sabotage. The plutonium content is too low to be of value either as weapons material or as a health hazard when dispersed. The high surface dose rate for all containers would require remote handling for normal operation, contributing to the overall inaccessibility of the waste. The compact metallic form of the waste would make effective dispersal of radioactive contaminants a difficult task. A successful incident, though unlikely, may be represented by the exposure of 200 kg of zirconium metal as bulk to the atmosphere and the subsequent release of radioactivity, as described under Accident 5.2.1. While serious, the consequences are not severe.

The physical protection given vital areas in an FRP while the fuel residue was accumulating during operation, and subsequently, for storage areas in other non-vital areas of the FRP would provide adequate safeguarding of this waste.

REFERENCES FOR SECTION 5.2

1. Nuclear Fuel Recovery and Recycling Center Preliminary Safety Analysis Report, Docket No. 54-564, XN-FR-32, Exxon Nuclear Company, Richland, WA, July 1976.

2. Alternatives for Managing Wastes From Reactors and Post-Fission Operations in the LWR Fuel Cycle, ERDA-76-43, Energy Research and Development Administration, Washington, DC, Vol. 1, May 1976.

3. Final Safety Analysis Report, Barnwell Nuclear Fuel Plant, Docket No. 50332-52, Amendment 6, Allied-General Nuclear Services, Barnwell, SC, August 1975.

5.3 NON-HIGH-LEVEL SOLID WASTE STORAGE

5.3 TRU NON-HIGH-LEVEL SOLID WASTE STORAGE

Closure of the light water reactor (LWR) fuel cycle by reprocessing spent fuel and recycling the recovered uranium and plutonium results in the generation of transuranic (TRU) non-high-level solid waste (NHLSW). Volumes and characteristics of these wastes, and methods for treating and packaging them, are presented in Sections 4.3, 4.4, and 4.7.

In this report, TRU NHLSW is classified into two categories according to its surface dose rate: 1) low-level waste (TRU LLW) that has surface radiation levels less than 200 mrem/hr and 2) intermediate-level waste (TRU ILW) that has surface radiation levels greater than 200 mrem/hr.

The annual quantities and average radioactivity content of the treated TRU NHLSW produced at the reference fuel reprocessing plant and MOX fuel fabrication plant (based on the reference treatment process defined in Section 3.4) are summarized in Table 5.3.1. The reference treatment processes include decontamination and disassembly of failed equipment, incineration of combustible wastes and cement immobilization of wet wastes and particulates. The radioactivity content of individual containers is expected to vary widely from the average compositions. This is indicated by the estimated range of surface dose rates compared to the average, as shown in the last column in the table.

In the event final waste isolation facilities (see Section 7.0) are not ready to accept the TRU NHLSW at the time of reprocessing, facilities for interim storage of these wastes would be required. Such storage facilities may be located where the waste is generated, i.e., fuel reprocessing or mixed oxide fuel fabrication plant or independent Federal sites that may be near the expected final isolation facility.

Alternative methods for interim storage of TRU NHLSW fall into two groups: outdoor and indoor.[1] In both the outdoor and indoor methods, waste can be stored either above or below the ground. Selection of appropriate storage methods depends primarily on the packaged form of the wastes, their radiation characteristics, the quantities to be stored, and relative costs. Reference storage methods for the two types of NHLSW, low-level and intermediate-level wastes, are discussed separately in the subsections that follow because of the differences in their characteristics and the resulting effects on storage.

Methods for interim storage of NHLSW must comply with the following criteria:

- Combustible and compactable portions of the waste are packaged separately and segregated from other waste types.
- Package labeling provides positive waste identification during the storage period.
- External package surfaces are reasonably free (as specified in applicable regulations) of smearable contamination; i.e., the removable (non-fixed) radioactive contamination on the outer surface of the waste package does not cause significant radiation exposure to operations personnel.
- Waste containers are readily retrievable in a contamination-free condition upon termination of interim storage.

TABLE 5.3.1. Quantities and Average Radioactivity Content of the Treated *Transuranic Non-High-Level Wastes Produced at the Reference* Fuel Reprocessing Plant and MOX Fuel Fabrication Plant

Description	Containers Per Year[a]	Average Radioactivity Content Per Container As a Fraction of Activity in One MTHM[b]			Range and Average Surface Dose Rate, R/hr
		Fission Products	Actinides	Activation Products	
Fuel Reproc. Plant TRU-LLW					
55-gal drums	2710	^{3}H = 1×10^{-10} ^{85}Kr = 0 ^{129}I = 1×10^{-4} Zr, Nb Ru & Rh = 7×10^{-8} Other = 1×10^{-8}	Pu = 6×10^{-5} Other = 4×10^{-5}	All = 7×10^{-10}	0.001 to 0.2 0.06 avg
4 ft x 6 ft x 6 ft boxes	60	^{3}H = 0 ^{85}Kr = 0 Other = 4×10^{-8}	All = 2×10^{-4}	None	0.001 to 0.1 0.08 avg
MOX-Fuel Fab. Plant TRU-LLW					
55-gal drums	2100	None	U & Pu = 4×10^{-4} Other = 8×10^{-4}	None	1×10^{-6} to 0.01 0.001 avg
4 ft x 6 ft x 6 ft boxes	20	None	All = 1×10^{-7}	None	5×10^{-5} avg
Fuel Reproc. Plant TRU-ILW					
55-gal drums	8170	^{3}H = 2×10^{-4} ^{85}Kr = 0 ^{129}I = 7×10^{-4} Zr, Nb Ru & Rh = 2×10^{-4} Other = 8×10^{-6}	U = 6×10^{-4} Pu = 9×10^{-4} Other = 8×10^{-6}	All = 5×10^{-5}	0.5 to 300 100 avg
30 in. dia x 10 ft canisters[c]	70	^{3}H = 0 ^{85}Kr = 0 Other = 7×10^{-7}	All = 7×10^{-7}	None	0.5 to 10 0.9 avg

a. Containers per year produced at reference 2000 MTHM/yr FRP or 400 MTHM/yr MOX FFP.
b. Multiply these fractions by the Ci/MTHM value for indicated nuclide to obtain the Ci/container value for the "average" container. The nuclide Ci/MTHM values can be found in Tables 3.3.6, 3.3.7, 3.3.9 and 3.3.15 for the FRP wastes and in Table 3.3.18 for the MOX FFP wastes.
c. These canisters are stored in the fuel residue storage facilities described in Section 5.2.

The four interim storage alternatives, along with their associated facilities, considered in this report are:

- outdoor surface storage of TRU low-level wastes
- indoor unshielded storage of TRU low-level wastes
- outdoor subsurface storage of TRU intermediate-level wastes
- indoor shielded storage of TRU intermediate-level wastes.

The report considers construction of such facilities at the following sites:

- the fuel reprocessing plant (FRP), with interim storage provided for NHLSW from the first 5 years of FRP operation
- the mixed oxide fuel fabrication plant (MOX FFP), with interim storage provided for NHLSW from the first 5 years of MOX FFP operation
- an independent Federal site, with interim storage provided for all NHLSW from all FRPs and MOX FFPs operating through the year 1990
- an independent Federal site, with interim storage provided for all NHLSW from all FRPs and MOX FFPs operating through the year 1995.

Facilities for storage of both LLW and ILW are required at the FRP and at the independent sites; only LLW storage facilities are needed at the MOX FFP.

Figure 5.3.1 shows the location of NHLSW storage facilities at the reference FRP. Facilities for low-level waste storage will be similarly located at the MOX FFP.

5.3.1 Outdoor Storage of Transuranic Low-level Waste

In 1970, the Atomic Energy Commission decided that all national defense program transuranic waste would be stored retrievably on an interim basis. One concept proposed for the storage of low-level wastes was above ground storage. This storage method is presently used by the Idaho National Engineering Laboratory (INEL) and by government installations at Hanford, Los Alamos, and Savannah River. Several variations are in use, mostly dealing with the amount of weather protection given to the wastes. The most widely accepted method is to place wastes onto some structural pad, cover them with an impermeable membrane and cover them with dirt. Though this method has not been tried commercially, experience gained at the various government laboratories has shown it to be sound.

5.3.1.1 Alternatives for Outdoor Storage of Transuranic Low-level Waste

Figure 5.3.2 illustrates possible outdoor storage concepts for solid TRU LLW. These concepts include: 1) totally exposed surface storage, 2) surface storage with plastic weather cover, 3) surface storage with plastic weather and earth cover, 4) below-grade, hole-in-ground storage, 5) below-grade trench storage, and 6) below-grade cave or mine storage. Concept 1, totally exposed surface storage, is limited exclusively to waste containers that have a 20-yr service life without additional protection. Concepts 2 and 3 provide some weather

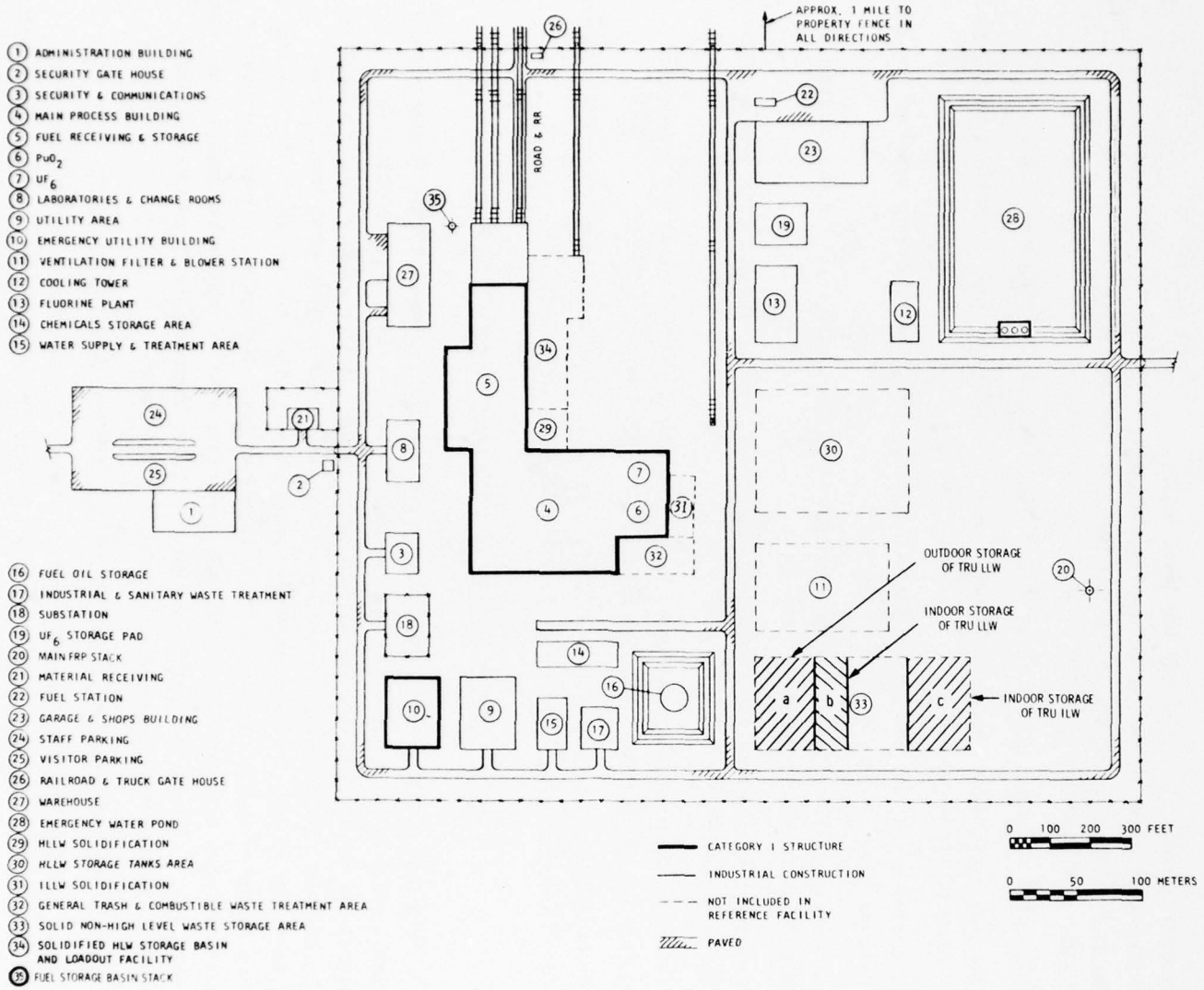


FIGURE 5.3.1. Location of Non-high-level Waste Storage Facilities at the Reference Fuel Reprocessing Plant

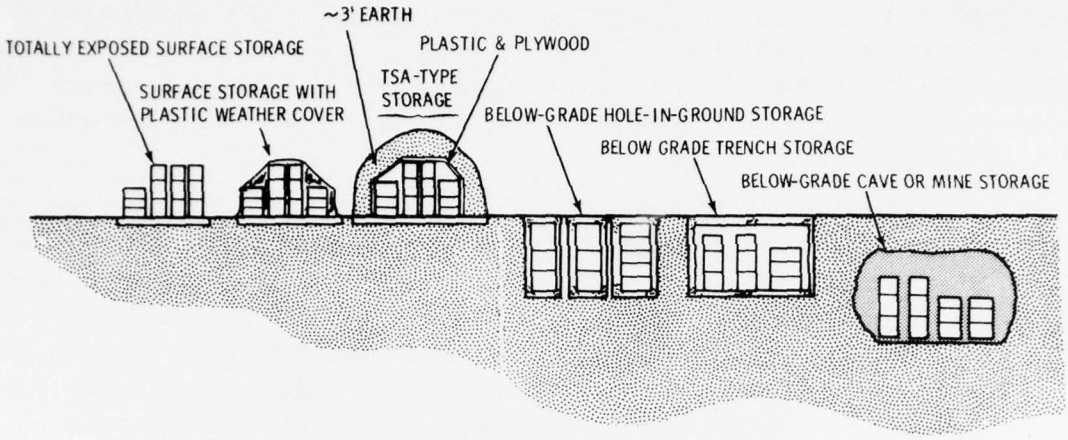


FIGURE 5.3.2. Outdoor Storage Concepts for Transuranic Low-Level Waste

protection so that waste containers having less than 20-yr service life capability in a totally exposed environment probably can be used. The three below-grade storage concepts, concepts 4-6, provide a certain amount of environmental protection for the waste container. Therefore, any one of the below-grade storage concepts may be used for waste containers that have 20-yr unprotected storage life, as well as for containers that need some protection to withstand 20-yr storage life.

Evaluation of the relative merits of these storage alternatives led to the selection of concept 3 as the reference alternative for outdoor storage of TRU LLW. Parameters considered in the comparison of the possible concepts include: facility costs, storage environment, camouflage characteristics, resistance to spread of fire, resistance to contamination spread from leakage, vandalism, versatility in accommodating waste containers, accessibility for in-storage inspection, and development requirements. The reference concept, which is known as transuranic storage area (TSA) storage, has been employed for TRU LLW generated at government facilities. This reference TSA is similar to that in use at INEL.

5.3.1.2 Design Basis for the Outdoor Storage Facility for Transuranic Low-level Waste

Outdoor storage facilities for TRU LLW are postulated for the four sites described above (see the introductory remarks to Section 5.3). The following assumptions have been made in the design of these facilities:

- For outdoor storage at the fuel reprocessing plant - The reference FRP has an annual generation rate of TRU LLW from facilities described in Sections 4.3, 4.4 and 4.7 of 2710 55-gal drums and 60 1.2 x 1.8 x 1.8 m (4 x 6 x 6 ft) boxes (see Table 5.3.1). A storage capacity equivalent to 15,000 55-gal drums is needed for the first 5 years of FRP operation. (In determining equivalent 55-gal drum capacity, one box is equal to 12 drums in terms of storage space required.)

- For outdoor storage at the mixed oxide fuel fabrication plant - The reference MOX FFP has an annual generation rate of TRU LLW from facilities described in Sections 4.3, 4.4 and 4.7 of 2100 55-gal drums and 20 1.2 x 1.8 x 1.8 m (4 x 6 x 6 ft) boxes. A storage capacity equivalent to 10,000 55-gal drums is needed for the first 5 years of MOX FFP operation.

- For outdoor storage at an independent site - Outdoor storage facilities at an independent site are designed with the capacity to store NHLSW generated by all operating FRPs and MOX FFPs. Two cases, A and B, are considered. Case A, which includes facilities to store TRU LLW generated through 1990, requires storage capacity equivalent to 70,000 55-gal drums; Case B, which includes facilities to store TRU LLW generated through 1995, requires a storage capacity equivalent to 140,000 55-gal drums. The required capacities are based on the assumed installation schedule for reactors, FRPs, and MOX FFPs presented in Section 3.10.

5.3.1.3 Operations at the Outdoor Storage Facility for Transuranic Low-level Waste

Figure 5.3.3 is an operations flow diagram for the reference outdoor storage facility for TRU LLW. Also listed in this figure are materials and equipment used during storage activities. Outdoor storage operations are identical for the FRP, MOX FFP and the independent sites.

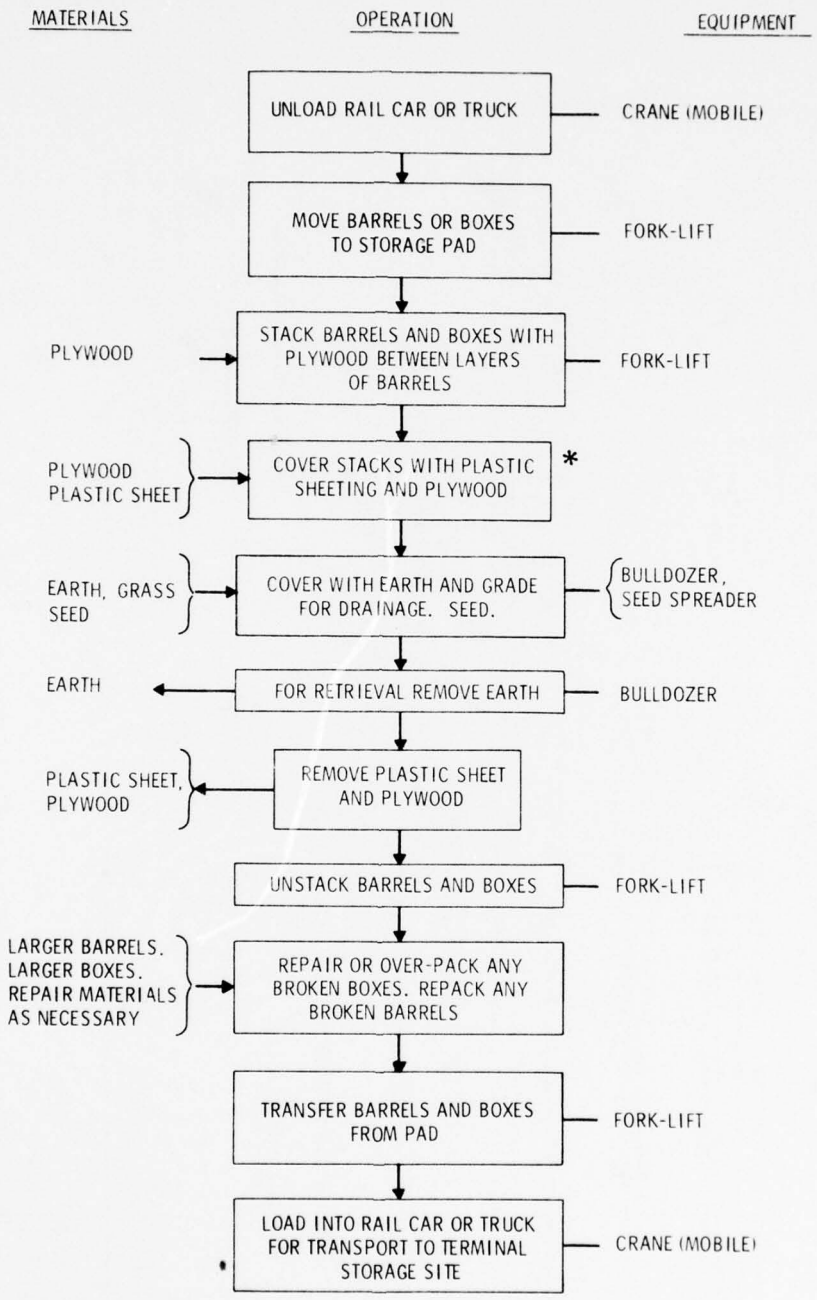
During storage operations, truck-transported waste drums arrive at the facility and are checked for loose contamination. Decontamination facilities are not provided at the outdoor storage site. Any waste packages received with loose contamination are returned to their point of origin for cleanup; contamination-free drums are immediately unloaded by the mobile crane and stacked by a drum grabber. The drums are arranged in horizontal layers; sheets of plywood are placed manually over each layer before another layer of drums is added.

As the storage area is filled, polyethylene sheets are laid over the stacked drums. Backfill material is hauled in by trucks over the access ramp and roads leading to either side of the facility. The bulldozer spreads the backfill from the outside toward the center until all the drums are covered with at least 0.91 m (3 ft) of fill. Once a storage area is filled and the drums are covered with earth, the temporary air-supported structure, installed over the storage area to permit storage operations during all weather conditions, is removed. The top of the fill is then either seeded or covered with a bitumen layer.

Operations are reversed to retrieve the LLW waste packages for shipment to a final repository.

5.3.1.4 Description of the Outdoor Storage Facility for Transuranic Low-level Waste

Figure 5.3.4 shows the basic storage module for the outdoor storage facility for TRU LLW. This module has a storage capacity of 10,000 55-gal drums of waste. When storage capacity beyond that provided by the basic module is required for a specific application, an expanded version of the basic module is used, or multiples of the module are added until the required capacity is reached.



*WHERE EQUIPMENT IS NOT INDICATED THE OPERATION IS DONE MANUALLY. WHERE EQUIPMENT IS INDICATED THE OPERATION MAY BE DONE ENTIRELY WITH EQUIPMENT OR WITH A COMBINATION OF MANUAL AND EQUIPMENT OPERATIONS.

FIGURE 5.3.3. Operations Flow Diagram for Outdoor Storage of Transuranic Low-level Waste

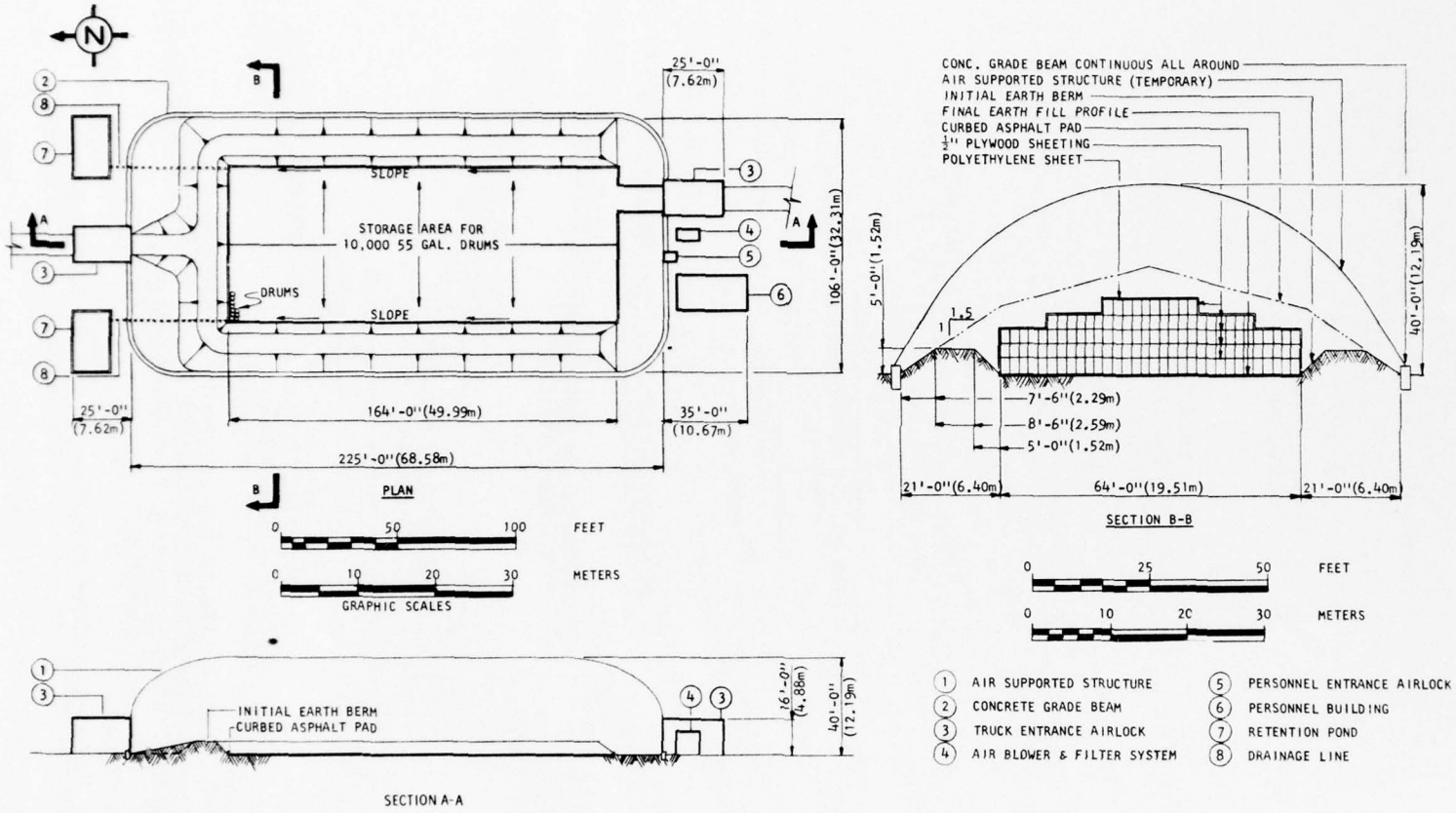


FIGURE 5.3.4. Outdoor Storage Facility for Transuranic Low-level Waste, Plan and Section View

The basic module is constructed around a curbed asphalt pad 19.5 m (64 ft) wide by 50 m (164 ft) long having a center crown to allow water to flow to the sides of the pad and drain to the retention ponds. Part of the final fill material is accumulated initially at three sides of the asphalt pad and is used to form a berm. An access road is provided on top of the berm for use during backfilling over the drums.

As mentioned earlier, a temporary air-supported structure is installed over the basic module, allowing storage operations to continue during inclement weather. The structure is 32 m (105 ft) wide, 69 m (226 ft) long, and 12 m (40 ft) high at its center. It incorporates ventilation and inflation equipment, two truck-size air locks and a personnel access door. A continuous concrete beam at grade level is required all around the area for anchorage.

Two plastic-lined retention ponds are provided for collection of water that drains from the asphalt pad. This water is monitored for radioactivity and released to the surface drainage system if not contaminated. Contaminated waste is transferred to the nearest waste treatment facilities.

A personnel building is provided for the convenience of the workers in the facility. It is a 5 m (16 ft) by 10 m (33 ft) light structural steel building with internal partitions. It is insulated and weather-proofed and contains an office, change room and wash room.

Major Equipment. For normal operation of the facility the following equipment is required.

- mobile yard crane
- fork-lift truck
- bulldozer
- portable lighting for the area.

Shielding and Remote Handling Equipment. Waste drums and boxes of TRU LLW do not require shielding. Drums are moved and stacked with a fork-lift truck equipped with a drum grabber. Boxes are moved on pallets by standard handling methods with the fork-lift truck.

5.3.1.5 Operating and Maintenance Requirements for the Outdoor Storage Facility for Transuranic Low-level Waste

Even at maximum operating requirements the required number of drums and boxes can be placed in storage at all facilities in one 8-hr shift per day. A crew of 2 operators and 1 radiation monitor can place 300 to 400 drums in storage in one 8-hr shift. Some additional time is required for storage preparations, securing stored drums and covering the wastes. Maximum drum placement requirements occurs at the independent site in 1995 and is equivalent to 64 drums/day. Requirements at the FRP and MOX FFP are in the range of 5 to 15 drums/day.

Staffing. Table 5.3.2 gives personnel requirements for outdoor storage of TRU LLW at the FRP, MOX FFP, and independent sites in 1990 and 1995. •

TABLE 5.3.2. Staffing Requirements for Outdoor Storage of Transuranic Low-level Waste

Job Description	Personnel Required, man-yr/yr			
			Independent Sites	
	FRP	MOX FFP	Case A[a]	Case B[b]
Operators	0.5	0.4	2	3
Radiation monitors	0.3	0.2	1	1
Maintenance craftsmen	0.6	0.05	0.2	0.3

a. For storing wastes generated through 1990.
b. For storing wastes generated through 1995.

Supplies and Utilities. Table 5.3.3 estimates supplies and utilities for the reference facilities at peak handling periods.

TABLE 5.3.3. Supplies and Utilities for the Outdoor Storage of Transuranic Low-level Waste

Item	Use Rate	Annual Requirement			
				Independent Site	
		FRP	MOX FFP	Case A[a]	Case B[b]
Electricity	100 kW	70 MW-hr	50 MW-hr	230 MW-hr	320 MW-hr
Diesel fuel	15 ℓ/hr	5,300 ℓ	3,800 ℓ	15,000 ℓ	23,000 ℓ
Plywood 1.27 cm	6.0 m^2/hr	1,000 m^2	700 m^2	3,400 m^2	4,700 m^2
Plastic sheet	2.3 m^2/hr	650 m^2	450 m^2	2,000 m^2	3,000 m^2

a. For storing wastes generated through 1990.
b. For storing wastes generated through 1995.

5.3.1.6 Secondary Radioactive Wastes for the Outdoor Storage Facility for Transuranic Low-level Waste

No secondary radioactive wastes are generated from routine operation of reference interim storage facilities.

5.3.1.7 Emissions from the Outdoor Storage Facility for Transuranic Low-level Waste

No chronic emissions are expected from routine operation of these facilities. In 6 years of storage at a surface storage facility at Idaho National Engineering Laboratory 73,000 containers have been handled and no releases have been detected. An infrequent very small release can be expected from minor accidents (see Table 5.3.4).

5.3.1.8 Decommissioning Considerations for the Outdoor Storage Facility for Transuranic Low-level Waste

The outdoor surface storage facilities are designed for gradual accumulation of TRU LLW for up to a 10-15 year period. The gradual transfer of the stored waste to a final repository takes a similar period. After removal of the stored waste, the facilities will be free of radioactive contamination and available for routine salvage procedures.

5.3.1.9 Postulated Accidents for the Outdoor Storage Facility for Transuranic Low-level Waste

For consideration of postulated accidents, the following assumptions were made regarding the TRU LLW in storage:

- The wastes are in a form suitable for final geologic isolation and package requirements may therefore be somewhat more restrictive than would be required for interim storage consideration alone.
- The wastes are packaged in sealed 55 or 80 gal drums of 1.2 x 1.2 x 1.8 m steel boxes.
- Particulate wastes are incorporated into a solid matrix, such as concrete or bitumen.
- Liquid wastes have been immobilized in concrete or bitumen.

Postulated minor and moderate accidents for outdoor storage of TRU LLW are presented in Tables 5.3.4 and 5.3.5, respectively. No accidents that could be classified as severe accidents could be realistically postulated for this technology. The breach of waste barrels has occurred at INEL. These minor breaches have led to no detectable release of radioactive material even though pretreatment and incorporation in a solid matrix is not required; however, to be conservative a release estimate was developed for this accident. No postulated moderate accidents have occurred in facilities of the type at INEL.

Two of the accidental releases have been designated as umbrella source terms. These accidents are 5.3.1 (Mechanical Breach of Drum) and 5.3.6 (Tornado Strikes). (See Section 3.7 for a description of umbrella accidents and Appendix 3A for a cross index listing of accidents and umbrella accidents by accident number.) A minor accident of the type described by accident 5.3.1 was estimated to expose 0.5% of the barrel contents, and one-half of 1% of the exposed material was estimated to be entrained in the atmosphere at ground level in 1/2 hr. The source term in Accident 5.3.6 involves the failure of three metal boxes by tornado pressure and impact forces. Waste placed in boxes tends to be large pieces of material with little release of radioactive materials. For this reason, it was estimated that only 0.1% of the radioactive material in the box would be entrained in the atmosphere. Solidified waste drums exposed to the tornado were assumed to remain on the ground due to their high mass and relatively small surface area. These exposed drums would receive minimal damage.

5.3.1.10 Costs for the Outdoor Storage Facility for Transuranic Low-Level Waste

Estimates have been made, in mid-1976 dollars, of capital, operating and levelized unit costs for outdoor storage of TRU LLW at the FRP, MOX FFP and an independent site. A description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Cost. Capital costs for outdoor storage facilities for TRU LLW at the FRP, the MOX FFP, and an independent site are based on the cost of the basic module, which has a capacity for 10,000 55-gal drums. The capital cost estimate for the basic outdoor storage module is shown in Table 5.3.6. This estimate covers all capital costs associated with

TABLE 5.3.4. Minor Accidents for the Outdoor Storage Facility for Transuranic Low-Level Waste

Accident No. and Description	Sequence of Events	Safety System	Release
5.3.1 – Mechanical breach of drum; expected frequency, 2 x 10^{-4} for each drum stored or retrieved.	1. Operator error may cause the fork from fork-lift truck to penetrate a 55-gal drum, or improper handling may result in a drum dropping to the asphalt surface. 2. Drum contents are exposed to the environment. 3. Contents of drum are repackaged. 4. Area is decontaminated.	1. Fork-lift is equipped with a drum grabber to avoid dropping. 2. Drums are designed to survive drops of 9 m when filled with 200 kg water.	A release fraction was estimated for the breached drum of 2.5 x 10^{-5} to the atmosphere at ground level. Table 5.3.1 describes the contents of drums filled at both the fuel reprocessing plant and mixed oxide fuel fabrication plant.
5.3.2 – Dislodge surface contamination.	1. Drum improperly decontaminated at source. 2. Surface contamination dislodged during drum handling. 3. Contamination detected. 4. Cleaning initiated.	1. Drums move through a decontamination and inspection process before shipment to storage. 2. Drums surveyed on arrival before handling.	Limited to work area, or less than Accident 5.3.1.
5.3.3 – Overpressurization of sealed containers.	1. Reactive material sealed in package. 2. Biological, radiolytic, or chemical reaction generates gas. 3. Gasket fails, releasing gases.	1. Reactive material not routinely packaged.	None, or less than Accident 5.3.1.
5.3.4 – Container rusts through.	1. Scratched container surface undetected. 2. Weathering causes rusting to expose contents.	1. Surface painted to protect against rust. 2. Scratches repainted.	None, or less than Accident 5.3.1.

TABLE 5.3.5. Moderate Accidents for the Outdoor Storage Facility for Transuranic Low-Level Waste

Accident No. and Description	Sequence of Events	Safety System	Release
5.3.5 – Fire in storage stack.	1. Gasoline leaks from equipment into uncovered stack. 2. Gasoline ignites. 3. Plywood and plastic in stack burns. 4. Fire detected. 5. Fire extinguished.	1. Equipment inspected routinely for defective fuel tanks. 2. Fire and smoke detection alarms. 3. Fire extinguishing equipment.	Less than Accident 5.3.6.
5.3.6 – Tornado strikes.	1. Tornado strikes storage pad. 2. Boxes and drums dislodged from partially completed stacks. 3. Boxes ruptured after being airborne. 4. Tornado subsides. 5. Collect stray waste containers.	1. Cover stack as storage progresses. 2. Containers designed to survive some impact and reduce releases.	Three metal boxes open during a tornado. It is estimated that 0.001 of the contents of each box is released to the atmosphere at ground level. Table 5.3.1 describes the contents of boxes filled at both the fuel reprocessing plant and mixed oxide fuel fabrication plant.

TABLE 5.3.6. Capital Cost Estimate for the Basic Outdoor Storage Module for Transuranic Low-level Waste

Cost Element	Man-hours 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		0.7	435	8	443
Buildings and structures		5.3	65	62	127
Bulk materials					
Site improvements					
Subtotal of direct site construction costs		6.0	500	70	570
Indirect site construction costs	2.0	1.0	25	35	60
Total field cost	2.0	7.0	525	105	630
Architect-engineer services					130
Subtotal					760
Owner's cost					240
Total facility cost					1000
Estimate accuracy range					±30%

incorporating the basic module in the FRP or MOX FFP described in Section 3.2. These costs also include the effect of additions to common facilities, such as the electrical substation, shops, and compressed air, attributable to the basic module. However, general FRP or MOX FFP costs for such services as laboratories and warehousing have not been allocated to the reference storage facility. The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of operations with the exception of working capital.

Capital costs for building additional storage modules are shown in Table 5.3.7. Once a basic module has been built, other modules may be added to increase storage capacity without incurring one-time expenses, such as the electrical substation, air support structure (except as noted in the table), slope, compressed air, equipment and personnel building. Thus, there is a significant cost scaling advantage for a large storage facility. For example, a facility with 10 times the basic module capacity costs only about 3 times as much.

The total capital cost for the reference outdoor storage facility for TRU LLW at the FRP will be slightly higher than that presented in Table 5.3.6 for the basic module. This is because, as stated earlier (Section 5.3.1.2), the facility at the FRP requires a storage capacity of 15,000 55-gal drums (versus basic module capacity of 10,000 drums) to handle all the TRU LLW generated during the first 5 years of FRP operation. The storage module at the FRP would, therefore, be an expanded version of the basic module, which has a storage capacity of only 10,000 drums. From costs for expansion given in Table 5.3.7, a capital cost estimate

TABLE 5.3.7. Capital Cost Estimate for Incremental Expansion of Basic Outdoor Storage Module for Transuranic Low-Level Waste

Number of Modules	Total Capacity, Number of 55-gal Drums	Total Capital Cost, $1000s
1	10,000	1,000
2	20,000	1,220
4	40,000	1,660
6	60,000	2,100
7	70,000	2,320
8	80,000	2,740[a]
10	100,000	3,180
12	120,000	3,620
14	140,000	4,060

a. On the eighth expansion, a new air support structure is required.

of $1,100,000 has been developed for the outdoor storage facility for TRU LLW at the FRP. The reference storage facility at the MOX FFP requires a capacity equal to that of the basic module; the capital cost for outdoor storage of TRU LLW at the MOX FFP is, therefore, the same as that given in Table 5.3.6.

Since the outdoor storage facility at an independent site is not an integral part of another facility with which it can share support services, the capital cost of providing such services must be added to the estimate given in Table 5.3.6 in order to obtain the total capital cost of constructing the basic outdoor storage module at an independent site. Table 5.3.8 gives the incremental capital cost estimate for support services for an independent storage facility.

The accuracy range of the estimates reflects uncertainties in the engineering scope required to provide a fully functional facility based on the technology described and in the pricing and quantities for labor, materials, and equipment. A contingency covering these and similar factors has been included in the base estimates. With the contingency included, there is an approximately equal likelihood of the indicated cost overrun or underrun.

The capital cost schedule for expanding the capacity of the independent outdoor facility to store TRU LLW through 1990 and through 1995 are shown in Table 5.3.9. The table also gives the schedule for capacity expansion and incorporates the incremental cost for support services given earlier in Table 5.3.8.

Operating Costs. The operating cost components for outdoor storage of transuranic low-level waste are shown in Table 5.3.10. Direct labor costs are based on manpower estimates given in Table 5.3.2. Process material and utility costs are derived from requirements shown in

TABLE 5.3.8. Incremental Capital Cost Estimate for Support Services for a Storage Facility at an Independent Site

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment			300		300
Buildings and structures		8	100	100	200
Bulk materials					
Site improvements		17	100	200	300
Subtotal of direct site construction costs		25	500	300	800
Indirect site construction costs	7	5	100	150	250
Total field cost	7	30	600	450	1050
Architect-engineer services					200
Subtotal					1250
Owner's cost					350
Total Incremental Facility Cost					1600
Estimate accuracy range					±25%

TABLE 5.3.9. Capital Cost Schedule for Expanding the Capacity for Outdoor Storage of Transuranic Low-level Waste at an Independent Site

Year	Capacity Expansion, Number of 55-gal Drums		Capital Cost Increase, $1000s	
	Case A(a)	Case B(b)	Case A(a)	Case B(b)
1981	10,000	10,000	2,600	2,600
1984	10,000	10,000	220	220
1986	10,000	10,000	220	220
1987	10,000	10,000	220	220
1988	10,000	10,000	220	220
1989	10,000	10,000	220	220
1990	10,000	10,000	210	220
1991	-	20,000	-	640(c)
1992	-	10,000	-	220
1993	-	10,000	-	220
1994	-	20,000	-	440
1995	-	10,000	-	220
Total	70,000	140,000	3,910	5,660

a. For storing wastes generated through 1990.
b. For storing wastes generated through 1995.
c. On the eighth expansion, a new air support structure is required.

TABLE 5.3.10. Operating Cost Estimate for Outdoor Storage of Transuranic Low-Level Waste

Cost Element	Annual Costs, $1000s			
			Independent Site	
	FRP	MOX FPP	Case A(a)	Case B(b)
Direct labor	13	10	110	110
Process materials	2	1	6	10
Utilities	2	1	6	9
Maintenance materials	10	9	19	34
Overhead	20	16	150	150
Miscellaneous	3	3	7	12
Total	50 +50% -25%	40 +50% -25%	300 +50% -25%	325 +50% -25%

a. For storing wastes generated through 1990.
b. For storing wastes generated through 1995.

Table 5.3.3. Annual maintenance materials costs are estimated at three percent of initial major equipment costs. Overhead and miscellaneous costs are estimated using the standard method described in Section 3.8. The estimates for the miscellaneous items are intended to include all unidentified operating costs. The cost of taxes, insurance, and interest are included in the capital charge segment of the levelized unit cost.

Operating costs for the storage facilities at the FRP and MOX FFP are based on waste quantities accumulated from 5 years of FRP and MOX FFP operation. Operating costs for the independent site facilities are based on waste quantities accumulated from all FRPs and MOX FFPs through the year 1990 (Case A) and 1995 (Case B).

Levelized Unit Costs. Table 5.3.11 lists the total levelized unit costs as well as the levelized capital and operating components. The cost calculations assume private ownership for facilities at the FRP and MOX FFP, and Federal ownership at the independent site. Calculations also assume a 15-year economic life. Capital costs for facility expansions at the independent site are assumed to be expended according to the Schedule in Table 5.3.9. The cost scaling advantage of larger capacity at the independent site is somewhat counterbalanced by the added cost of support service facilities.

TABLE 5.3.11. Levelized Unit Cost Estimate for Outdoor Storage of Transuranic Low-Level Waste

Cost Element	Unit Cost, Dollars/kgHM(a)			
			Independent Site	
	FRP	MOX FFP	Case A(b)	Case B(c)
Levelized capital charge	0.30	1.45	0.25	0.20
Levelized operating charge	0.05	0.15	0.05	0.05
Levelized total unit cost	0.35 ±30%	1.60 ±25%	0.30 ±25%	0.25 ±25%

a. Unit costs are based on units of spent fuel reprocessed at the FRP and on units of MOX fuel fabricated at the MOX FFP. To convert $/kgHM MOX fuel to $/kgHM reprocessed, divide by 5.
b. For storing waste generated through 1990.
c. For storing waste generated through 1995.

5.3.1.11 Construction Requirements for Outdoor Storage of Transuranic Low-level Waste

Many factors related to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. Except where specified, information in this section is for the outdoor storage facility basic storage module, and assumes that the basic module is integrated into the original design and construction of the FRP or MOX FFP. Requirements for facilities that incorporate expansions of the basic module may be approximated by linear extrapolation according to capacity.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of the basic module is an integral factor in the overall schedule for the design and construction of the FRP and MOX FFP. The field labor force estimated for module construction is as follows:

	Man-hours, 1000s
Manual field labor	7
Nonmanual field labor	2
Total field labor	9

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP or MOX FFP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is as follows:

	Costs, $1000s	
	Basic Module	Independent Site Support Services
Onsite	200	500
Offsite	800	1100
Total	1000	1600

Site Requirements. Outdoor storage of TRU LLW requires 0.36 ha (0.9 acres) within the FRP site and 0.24 ha (0.6 acres) within the MOX FFP site. Land requirements for an independent site are estimated to be 1.6 ha (4 acres) for Case A (1990) and 3.2 ha (8 acres) for Case B (1995). The independent site would preferably be located near a potential site for a final repository.

Water. Approximately 110 m^3 (3 x 10^4 gal) of water are required during the construction period.

Construction Materials. Materials committed to basic module construction are:

Concrete	76 m^3	(100 yd^3)
Steel	36 MT	(40 tons)
Copper	.9 MT	(1 ton)
Lumber	10 m^3	(4 MFBM)

Energy. Energy resources used during construction are:

Propane	1.1 m^3	(300 gal)
Diesel fuel	11 m^3	(3000 gal)
Gasoline	7.6 m^3	(2000 gal)
Electricity		
Peak demand	negligible	
Total consumption	negligible	

Transportation Requirements. No separate transportation requirements for the outdoor storage facility for TRU LLW are identified beyond those for the reference FRP or MOX FFP. A two-lane paved road to a U.S. highway is required for an independent site.

5.3.1.12 Effects of Fuel Cycle Options

The facilities for outdoor storage of TRU LLW are based on reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. The effects of alternative fuel cycles on these facilities are summarized below.

No Recycle. No TRU LLW will be generated if the FRP is eliminated. Storage facilities of this type would not be needed.

Uranium Recycle Only, with Plutonium to a Repository. The elimination of the MOX FFP with this fuel cycle option significantly reduces the volume of TRU LLW. The required capacity of the facility at an independent site would be significantly reduced. No significant change in the required capacity for the FRP is anticipated.

Uranium Recycle Only, with Plutonium to High Level Waste. The effects of this fuel cycle option should be about the same as for uranium recycle only, with plutonium to a repository.

5.3.2 Indoor Unshielded Storage of Transuranic Low-level Waste

The retrievable storage of LLW for extended periods is a recent development, as mentioned in Section 5.3.1. However, the use of an interim storage step for LLW for short periods at the point of its generation is a routine operation. Nuclear facilities, both commercial and government, have stored LLW for a short time prior to its shipment as a matter of practicality, ensuring that a full shipment of LLW is in inventory to gain maximum utilization of transportation equipment. At present, Oak Ridge National Laboratory (ORNL) is using indoor interim storage of LLW on a long-term basis, while INEL is developing that capability. The concept is quite simple, requiring no special handling equipment for LLW. The construction of a traditional warehouse is sufficient to meet storage needs. Variations in the concept are mostly in the choice of structural materials.

5.3.2.1 Alternatives for Indoor Storage Concepts of Transuranic Low-level Waste

Alternatives for indoor storage of TRU LLW primarily involve materials and methods for constructing the storage facility. Possible construction materials include: 1) reinforced concrete, 2) wood, 3) metal and 4) coated fabric. Corresponding construction methods include: 1) precast concrete, cast-in-place concrete or concrete block; 2) wood frame; 3) metal frame;

4) air-supported or structurally-supported coated-fabric buildings. A precast concrete indoor storage facility has been selected as the reference concept for this report. Among the parameters considered in making this choice were relative cost, maintenance, ease of decontamination, ease of dismantling, service life, salvage value, and resistance to fire, wind and rain.

5.3.2.2 Design Basis for the Indoor Storage Facility for Transuranic Low-level Waste

The design basis for the indoor storage facility for TRU LLW is the same as that presented in Section 5.3.1.2.

5.3.2.3 Operations at the Indoor Storage Facility for Transuranic Low-level Waste

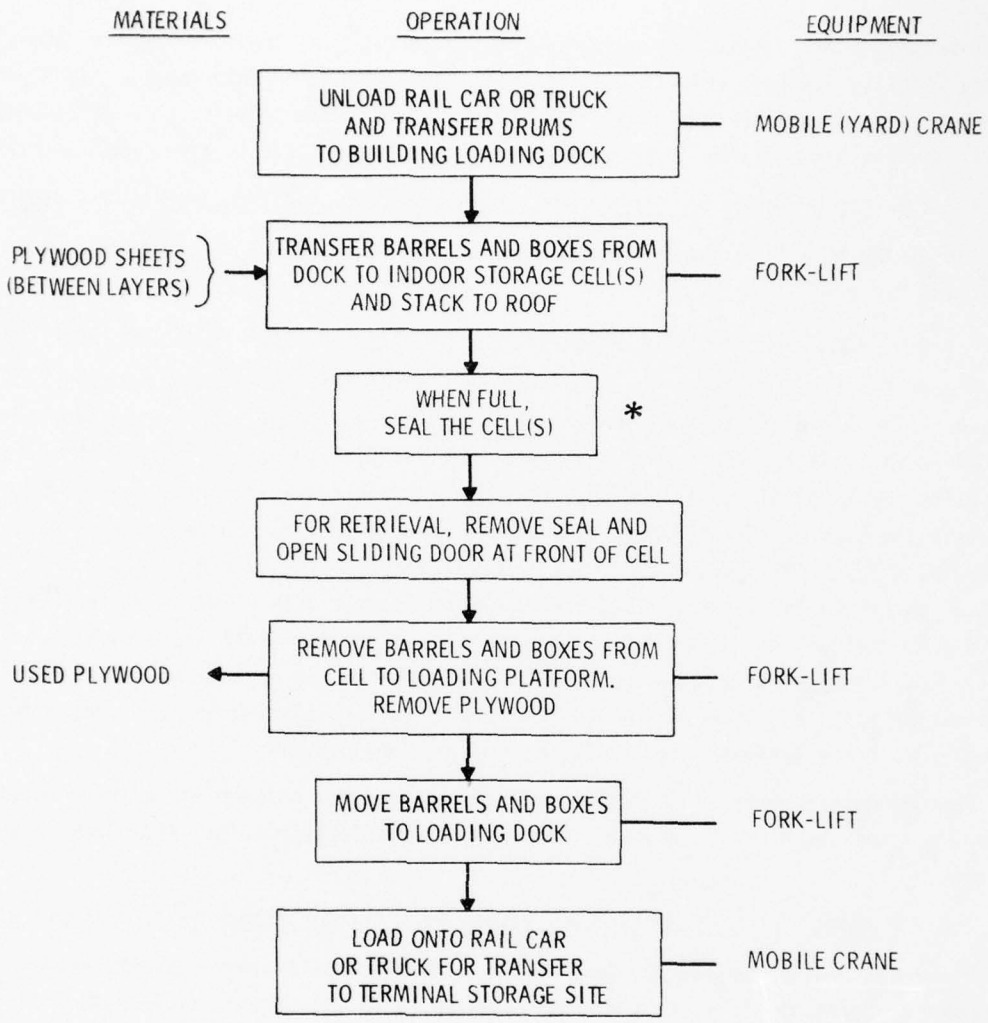
Figure 5.3.5 is an operations flow diagram for the reference indoor storage facility for TRU LLW. Also listed in this figure are materials and equipment used during storage activities. For the facility at the FRP or MOX FFP, waste may arrive either palletized, with several drums per pallet, or in single containers on the drum transport vehicle. At the independent site, the waste packages may be delivered by rail car or by truck. A mobile crane is used to unload the drums; the fork-lift truck then moves them to the cell for storage. Drums are stacked six high in horizontal layers. They are moved and stacked with a fork-lift truck equipped with a drum grabber. Boxes on pallets are moved with the fork-lift truck by standard handling methods. Plywood sheets are manually placed between each layer. A storage box occupies the space of 12 drums. After the cell is full, a sliding door is closed and sealed. Drums are inspected and monitored through roof hatches.

Operations are reversed to retrieve waste packages for shipment to a final repository. Storage and retrieval operations are identical for facilities in the FRP, MOX FFP and independent site.

5.3.2.4 Description of the Indoor Storage Facility for Transuranic Low-level Waste

The reference indoor storage facility is a modular, thin-slab, precast, reinforced concrete structure designed to store solid low-level waste in 55-gal carbon steel drums and 1.2 x 1.8 x 1.8-m (4 x 6 x 6-ft) steel boxes. Figure 5.3.6 shows the layout and details for the basic storage module. This module has a capacity to store 8400 drums in two cells 12 m (40 ft) wide by 21 m (70 ft) long. When storage capacity beyond that provided by the basic module is required for a specific application, an expanded version of the basic module is used, or multiples of the module are added until the required capacity is reached. Figure 5.3.7 illustrates the reference facility expanded to include ten storage cells.

The two cells in the basic module are constructed adjacent to a corridor 3 m (10 ft) wide with sliding doors for cell access. Each cell has interior lighting at roof level, with switch panels located on the outside. The floor level of the module is raised 0.91 m (3 ft) above the surrounding grade to facilitate the unloading of drums at the dock area. The dock itself is a light concrete structure that is easily detached from the storage facility when new cells are



* *WHERE EQUIPMENT IS NOT INDICATED THE OPERATION IS DONE MANUALLY. WHERE EQUIPMENT IS INDICATED THE OPERATION MAY BE DONE ENTIRELY WITH EQUIPMENT OR WITH A COMBINATION OF MANUAL AND EQUIPMENT OPERATIONS.*

FIGURE 5.3.5. Operations Flow Diagram for Indoor Storage of Transuranic Low-level Waste

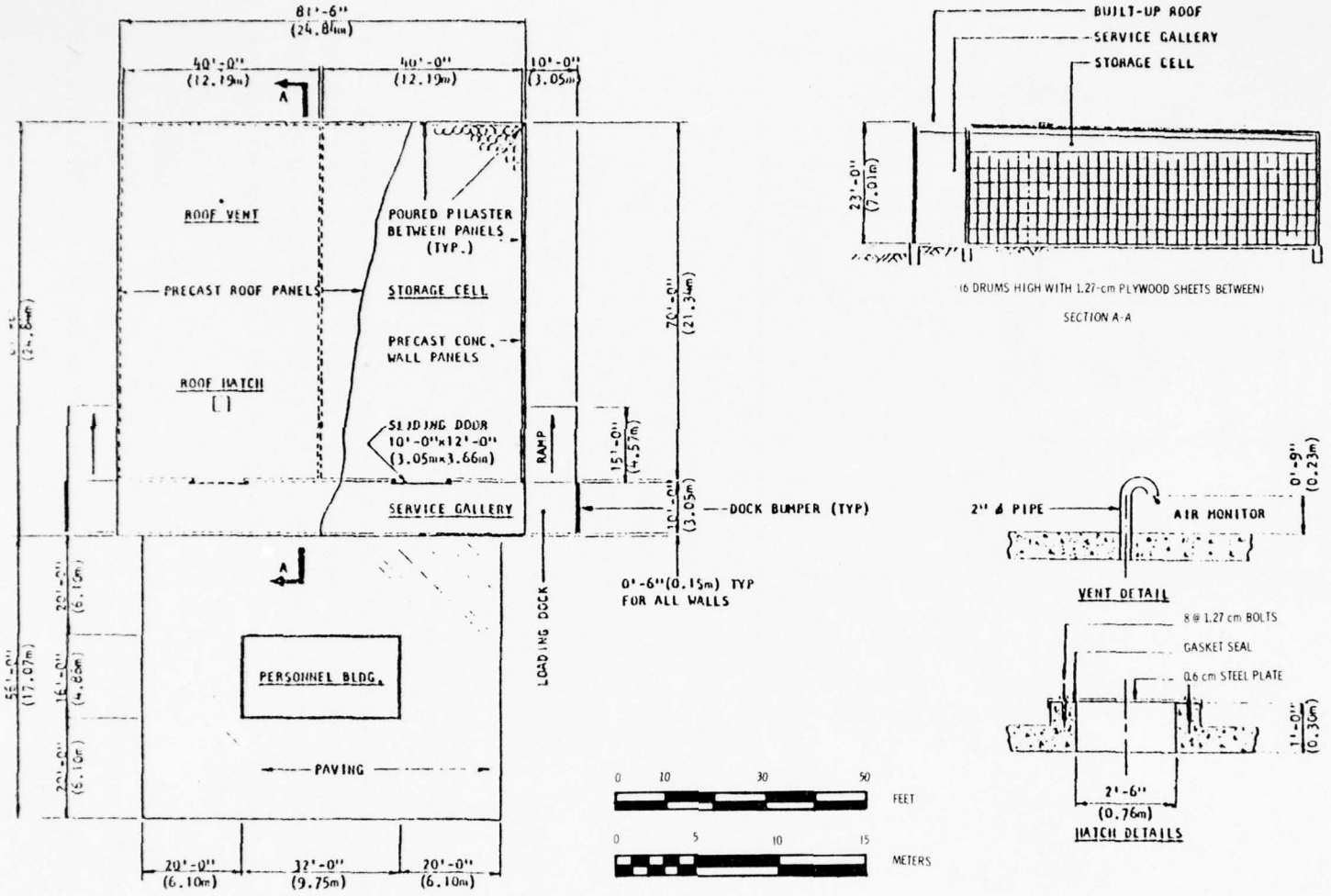


FIGURE 5.3.6. Indoor Storage Facility for Transuranic Low-level Waste, Basic Module Plan, Section and Details

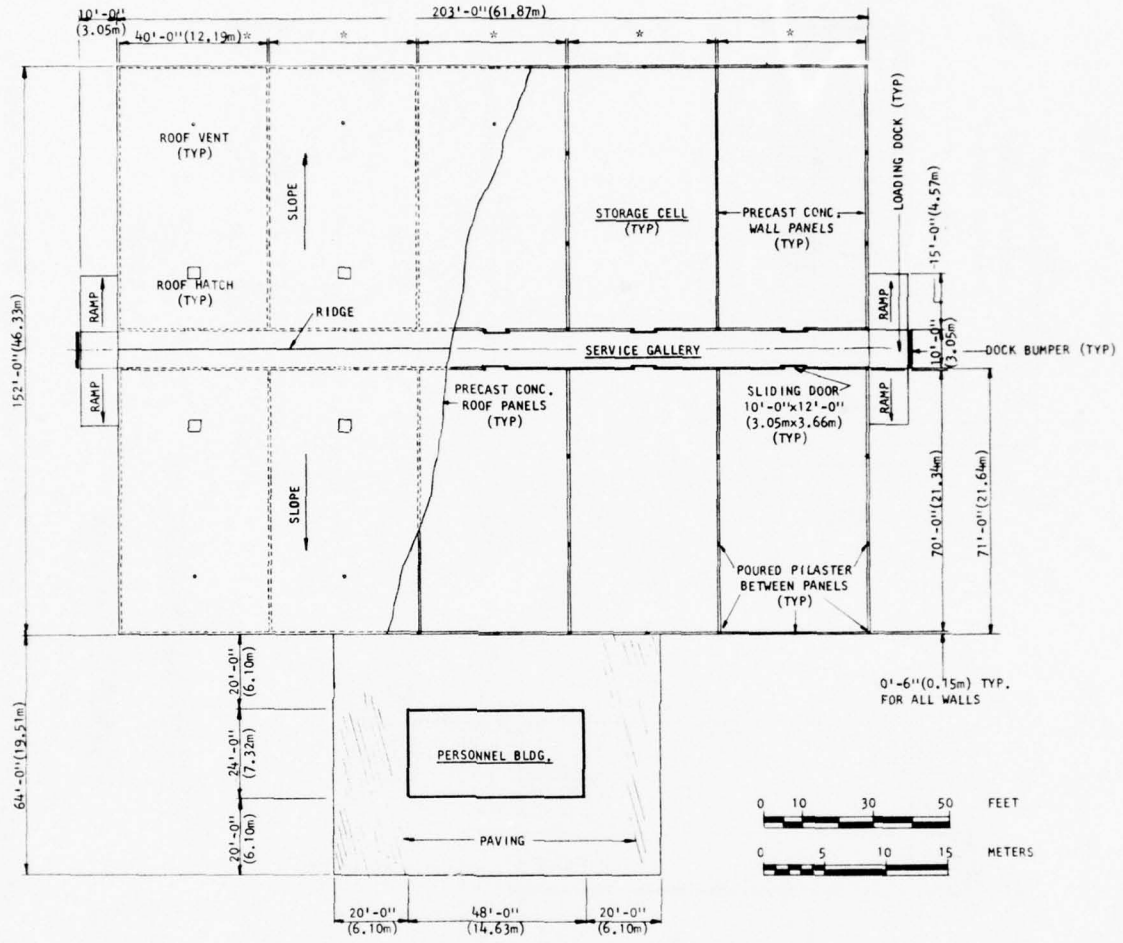


FIGURE 5.3.7. Indoor Storage Facility for Transuranic Low-level Waste, 10-Cell Plan

added. Forced air ventilation is not required for the stored waste; natural air circulation is provided by roof vents and cell wall openings. The personnel building is a prefabricated structural building with internal partitions and has a change room, wash room, and office.

Major Equipment. The following equipment is required for normal operation of the indoor storage facility:

- mobile crane
- fork-lift truck
- drum transport vehicle.

Shielding and Remote Handling Equipment. Waste drums and boxes of TRU LLW do not require shielding or remote handling.

5.3.2.5 Operating and Maintenance Requirements for the Indoor Storage Facility for Transuranic Low-level Waste

Even at maximum operating requirements the required number of drums and boxes can be placed in storage at all facilities in one 8-hr shift per day. A crew of 2 operators and 1 radiation monitor can place 300 to 400 drums in storage in a single 8-hr shift. Some additional time is required for storage preparation, monitoring of stored packages, securing stored drums, and sealing storage cells. Maximum drum placement requirement occurs at the independent site in 1995 and is equivalent to 64 drums/day. Requirements at the FRP and the MOX FFP are in the range of 5 to 15 drums/day.

Staffing. Personnel requirements for indoor storage are the same as for outdoor storage as given in Table 5.3.2.

Supplies and Utilities. Table 5.3.12 estimates supplies and utilities required for the reference indoor storage facilities for TRU LLW at peak handling periods.

TABLE 5.3.12. Supplies and Utilities for Indoor Storage of Transuranic Low-level Waste

		Annual Requirement			
				Independent Site	
Item	Use Rate	FRP	MOX FFP	Case A(a)	Case B(b)
Electricity	100 kW	70 MW-hr	50 MW-hr	230 MW-hr	320 MW-hr
Diesel fuel	11 ℓ/hr	2,600 ℓ	1,900 ℓ	7,600 ℓ	11,300 ℓ
Plywood, 1.27 cm	6 m^2/hr	1,400 m^2	900 m^2	4,600 m^2	6,500 m^2

a. For storing wastes generated through 1990.
b. For storing wastes generated through 1995.

5.3.2.6 Secondary Radioactive Wastes for the Indoor Storage Facilities for Transuranic Low-level Waste

No secondary radioactive wastes are generated from routine operation of reference interim storage facilities.

5.3.2.7 Emissions from the Indoor Storage Facility for Transuranic Low-level Waste

No chronic emissions are expected from routine operation of the reference facilities. Waste packages are designed to contain the waste for at least 20 years. An infrequent very small release can be expected from minor accidents (see Table 5.3.4).

5.3.2.8 Decommissioning Considerations for the Indoor Storage Facility for Transuranic Low-level Waste

The indoor storage facilities are designed for interim storage of TRU LLW for up to a 10 to 15 year period, followed by a similar period for transfer of the stored waste to a final repository. After removal of the stored wastes, the facilities will be free of radioactive contamination and available for routine salvage procedures.

5.3.2.9 Postulated Accidents for the Indoor Storage Facility for Transuranic Low-level Waste

For consideration of postulated accidents, the assumptions concerning the TRU LLW in storage are the same as those listed in Section 5.3.1.9. Postulated minor accidents are given in Table 5.3.13. Fire is a minor accident for indoor storage since fireproof construction materials are used and automatic fire detection and fire protection systems can be installed. No accidents that could be classifed as moderate or severe accidents could be realistically postulated for this technology.

TABLE 5.3.13. Minor Accidents for the Indoor Storage Facility for Transuranic Low-level Waste

Accident No. and Description	Sequence of Events	Safety System	Release
5.3.1 — Mechanical breach of drum; expected frequency, 2×10^{-4} for each drum stored or received.	1. Operator error may cause the fork from fork-lift truck to penetrate a 55-gal drum, or improper handling may result in a drum dropping to the asphalt surface. 2. Drum contents are exposed to the environment. 3. Contents of drum are repackaged. 4. Area is decontaminated.	1. Fork-lift is equipped with a drum grabber to avoid dropping. 2. Drums are designed to survive drops of 9 m when filled with 200 kg water.	A release fraction was estimated for the breached drum of 2.5×10^{-5} to the atmosphere at ground level. Table 5.3.1 describes the contents of drums filled at both the fuel reprocessing plant and mixed oxide fuel fabrication plant.
5.3.2 — Dislodge surface contamination.	1. Drum improperly decontaminated at source. 2. Surface contamination dislodged during drum handling. 3. Contamination detected. 4. Cleaning initiated.	1. Drums decontaminated and inspected before shipment to storage. 2. Drums surveyed on arrival before handling.	Limited to work area, or less than in 5.3.1.
5.3.3 — Overpressurization of sealed containers.	1. Reactive material sealed in package. 2. Biological, radiolytic, or chemical reaction generates gas. 3. Gasket fails, releasing gases.	1. Reactive material not routinely packaged.	None, or less than in 5.3.1.
5.3.4 — Container rusts through.	1. Scratched container surface undetected. 2. Weathering causes rusting to expose contents.	1. Surface painted to protect against rust. 2. Scratches repainted.	None, or less than in 5.3.1.
5.3.7 — Fire in storage stack.	1. Gasoline leak next to storage stack. 2. Gasoline ignites. 3. Plywood in stack burns. 4. Fire protection system actuated. 5. Fire extinguished.	1. Equipment inspected routinely for defective fuel and tanks. 2. Automatic fire and smoke detection alarms. 3. Automatic and manual fire protection systems.	None, or confined to building.

5.3.10 Costs for the Indoor Storage Facility for Transuranic Low-level Waste

Estimates have been made, in mid-year 1976 dollars, of capital, operating, and levelized unit costs for indoor storage of TRU LLW at the FRP, MOX FFP and an independent site. A description of the cost estimate bases, assumptions, and definition is given in Section 3.8.

Capital Cost. Capital costs for indoor storage facilities for TRU LLW at the reference sites are based on the cost of the basic module, which has a storage capacity of 8400 55-gal drums. The capital cost estimate for the basic indoor storage module is shown in Table 5.3.14. This estimate covers all capital costs associated with incorporating the basic module into the FRP or MOX FFP. The estimate also includes the cost of additions to common services, such as electrical supply from the substation, steam, water and compressed air, as well as bulk materials for electrical and instrument tie-ins with the reference FRP or MOX FFP. However, general FRP or MOX FFP costs for such services as laboratories, personnel facilities, health physics support, warehousing, shops, and administration buildings are not allocated to the storage facility. The total capital cost includes all facility-related costs incurred from the start of engineering to the initiation of storage operations with the exception of working capital.

TABLE 5.3.14. Capital Cost Estimate for the Basic Indoor Storage Module for Transuranic Low-level Waste

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment			60		60
Buildings and structures		17	120	210	330
Bulk materials					
Site improvements		—	—	—	—
Subtotal of direct site construction costs		17	180	210	390
Indirect site construction costs	5	3	80	100	180
Total field cost	5	20	260	310	570
Architect-engineer services					100
Subtotal					670
Owner's cost					230
Total facility cost					900
Estimate accuracy range					±25%

Table 5.3.15 gives the capital costs for building additional storage modules. Once the basic module has been built, other modules may be added to increase storage capacity without one-time costs such as electrical substation, personnel support building, shops, compressed air, and equipment. The cost for the first addition is slightly less than for subsequent additions because the service gallery aisle is in place with the first two cells. As in the case of outdoor storage, Table 5.3.7, the reduced cost of added modules results in a cost scaling advantage for a large storage facility; however, the advantage is not as great. For example, a 10 fold expansion costs about 6 times as much as the basic module.

TABLE 5.3.15. Capital Cost Estimate for Incremental Expansion of Basic Indoor Storage Module for Transuranic Low-level Waste

Number of Modules	Total Capacity Number of 55-gal Drums	Total Capital Costs, 1000s of Mid-1976 Dollars
1	8,400	900
2	16,800	1,340
4	33,600	2,260
6	50,400	3,180
8	67,200	4,100
10	84,000	5,020
12	100,800	5,940
14	117,600	6,860
16	134,400	7,780

The total capital cost for the reference indoor storage facility for TRU LLW at the FRP will be higher than that presented in Table 5.3.14 for the basic module. As stated earlier (Section 5.3.2.2), the facility at the FRP requires a storage capacity of 15,000 55-gal drums to handle all the TRU LLW generated during the first five years of FRP operation. The storage module at the FRP would, therefore, be an expanded version of the basic module, which has a storage capacity of only 8400 drums. Use of the cost for expansion given in Table 5.3.15 gives a capital cost estimate of $1,300,000 for the indoor storage facility for TRU LLW at the FRP. The reference storage facility at the MOX FFP, with a capacity of 10,000 55-gal drums, would also incorporate an expanded version of the basic module. A capital cost estimate of $1,000,000 has been developed for the indoor storage facility for TRU LLW at the MOX FFP.

Since the indoor storage facility at an independent site is not an integral part of another facility with which it can share support services, the capital cost of providing such services must be added to the estimate given in Table 5.3.14 in order to obtain the total capital cost of constructing the basic indoor storage module at an independent site. Table 5.3.8 gives the incremental capital cost estimate for support services for an independent storage facility.

The accuracy range for these estimates reflects uncertainties in the engineering scope required to provide a fully functional facility based on the technology described and in the pricing and quantities for labor, materials, and equipment. A contingency covering these and similar factors has been included in each of the base estimates. With the contingency included, there is an approximately equal likelihood of the indicated cost overrun or underrun.

The capital cost schedule for expanding the capacity of the independent indoor facility to store TRU LLW through 1990 and through 1995 is given in Table 5.3.16. This table also shows the schedule for capacity expansion and incorporates the incremental cost for support services given in Table 5.3.8.

TABLE 5.3.16. Capital Cost Schedule for Expanding the Capacity for Indoor Storage of Transuranic Low-level Waste at an Independent Site

Year	Capacity Expansion, Number of 55-gal Drums		Capital Cost Increase, $1000s	
	Case A(a)	Case B(b)	Case A(a)	Case B(b)
1981	8,400	8,400	2,500	2,500
1984	8,400	8,400	440	440
1985	8,400	8,400	460	460
1986	8,400	8,400	460	460
1987	8,400	8,400	460	460
1988	8,400	8,400	460	460
1989	8,400	8,400	460	460
1990	11,200	16,800	650	920
1991		8,400		460
1992		8,400		460
1993		16,800		920
1994		16,800		920
1995		14,000		880
Total	70,000	140,000	5,870	9,720

a. For storing wastes generated through 1990.
b. For storing wastes generated through 1995.

Operating Costs. The operating cost components for the indoor storage facility for TRU LLW are shown in Table 5.3.17. Direct labor costs are based on manpower estimates given in Table 5.3.2. Process material and utility costs are derived from requirements shown in Table 5.3.12. Annual maintenance materials costs are estimated at three percent of initial major equipment costs. Overhead and miscellaneous costs are estimated using the standard method described in Section 3.8. The estimates for miscellaneous items are intended to include all unidentified operating costs. The cost of taxes, insurance, and interest are included in the capital charge segment of the levelized unit cost.

TABLE 5.3.17. Operating Cost Estimate for Indoor Storage of Transuranic Low-level Waste

Cost Element	Annual Costs, $1000s			
			Independent Site	
	FRP	MOX FFP	Case A(a)	Case B(b)
Direct labor	13	10	110	110
Process materials	2	2	8	11
Utilities	2	1	6	7
Maintenance materials	2	1	5	10
Overhead	15	12	150	150
Miscellaneous	6	4	12	22
Total	40 +50% -25%	30 +50% -25%	285 +50% -25%	310 +50% -25%

Operating costs for storage facilities at the FRP and MOX-FFP are based on waste quantities accumulated from 5 years of FRP and MOX-FFP operation. Operating costs for the independent site facilities are based on waste quantities accumulated from all FRPs and MOX-FFPs through the year 1990 (Case A) and 1995 (Case B), respectively.

Levelized Unit Costs. Table 5.3.18 lists the total levelized unit cost, as well as the levelized capital and operating components. The cost calculations assume private ownership of FRP and MOX-FFP storage facilities, and Federal ownership at the independent site. Calculations also assume a 15-year economic life. Capital costs for facility expansions at the independent site are assumed to be expended according to the schedule in Table 5.3.16. Costs for this indoor storage concept are nearly the same as those for the outdoor storage concept. The cost scaling advantage of larger capacity at the independent site is counterbalanced by the added cost of support service facilities.

TABLE 5.3.18. Levelized Unit Cost Estimate for Indoor Storage of Transuranic Low-level Waste

	Unit Cost, $/kgHM[a]			
			Independent Site	
Cost Element	FRP	MOX-FFP	Case A[b]	Case B[c]
Levelized capital charge	0.35	1.45	0.30	0.25
Levelized operating charge	0.05	0.15	0.10	0.10
Levelized total unit cost	0.40 ±30%	1.60 ±25%	0.40 ±25%	0.35 ±20%

a. Unit costs are based on units of spent fuel reprocessed at the FRP and on units of MOX fuel fabricated at the MOX FFP. To convert $/kgHM MOX fuel to $/kgHM reprocessed, divide by 5.
b. For storing wastes generated through 1990.
c. For storing wastes generated through 1995.

5.3.2.11 Construction Requirements for Indoor Storage of Transuranic Low-level Waste

Many factors related to site preparation and reference facility construction have some impact on the environment, the local economy, and natural resources of the surrounding area. Except where specified, the information given in this section is for the indoor storage facility basic storage module, and assumes that the basic module is integrated into the original design and construction of the reference FRP and MOX FFP. Requirements for facilities that incorporate expansions of the basic module may be approximated by linear extrapolation according to facility capacity.

Project Schedule and Construction Manpower. The schedule for engineering procurement and construction of the indoor storage facility basic module is an integral factor in the overall schedule for the FRP or MOX FFP. The field labor force estimated for the construction of the storage module is tabulated below:

	Man-hours, 1000s
Manual field labor	20
Nonmanual field labor	5
Total field labor	25

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP or MOX FFP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is shown below:

	Costs, $1000s
Onsite	300
Offsite	600
Total	900

Site Requirements. Indoor storage of TRU LLW requires 0.16 ha (0.4 acres) within the FRP site and 0.12 ha (0.3 acres) within the MOX FFP site. Land requirements for an independent site are estimated to be about 0.53 ha (1.3 acres) for Case A (1990) and 1 ha (2.5 acres) for Case B (1995). The independent site would preferably be located near a potential site for a final repository.

Water. Approximately 380 m^3 (1 x 10^5 gal) of water are required during the construction period.

Construction Materials. Materials committed to basic module construction are:

Concrete	460 m^3	(600 yd^3)
Steel	60 MT	(70 tons)
Lumber	7 m^3	(3 MFBM)

Energy. Energy resources used during construction are:

Propane	4 m^3	(1,000 gal)
Diesel fuel	38 m^3	(10,000 gal)
Gasoline	19 m^3	(5,000 gal)
Electricity		
Peak demand	30 kW	
Total consumption	20,000 kWh	

Transportation Requirements. No separate transportation requirements for the indoor storage facilities have been identified beyond those for the reference FRP and MOX FFP. A two-lane paved road to a U.S. highway is required for the independent site.

5.3.2.12 Effects of Fuel Cycle Options

Effects of alternative fuel cycles are identical to those discussed in Section 5.3.1.12.

5.3.3 Outdoor Storage of Transuranic Intermediate-level Waste

The 1970 AEC directive for the retrievable storage of defense program TRU wastes has required development of a shielded storage concept for ILW. Below-grade outdoor storage concepts for TRU ILW are in use or are being developed at each major government nuclear installation. The concept, in general, calls for the placement of TRU ILW in a buried structural sleeve, usually concrete or steel. There is no commercial experience in performing this storage step.

5.3.3.1 Alternatives for Outdoor Subsurface Storage of Transuranic Intermediate-level Waste

The outdoor storage concepts for TRU ILW are the same as those presented in Figure 5.3.2 for LLW except that the exposed surface storage and the plastic weather cover concepts would only be applicable if the containers themselves are individually shielded. The totally exposed surface storage concept is applicable only to storage of waste containers that can withstand 20-yr storage life without protection and is not readily suitable for drums that require shielding and remote handling. The below-grade storage concepts are applicable, in theory, to any of the shielded or unshielded waste containers.

For waste packaged in unshielded containers, the hole-in-ground and below-grade trench storage concepts are superior to all of the other concepts considered. If the quantity of ILW to be placed into interim storage is large, the high cost of the shielded containers would be prohibitive compared with the cost of unshielded containers that are handled and shipped in reusable shielded over-pack casks.[1] For this reason, and because storage of ILW in shielded containers is substantially identical with storage of LLW already discussed in Section 5.3.1, only the ILW packaged in unshielded containers is considered in this section. After evaluation of alternatives for outdoor storage of ILW and some related experience at INEL, the below-grade, hole-in-ground storage concept was selected as the reference concept for outdoor storage.

5.3.3.2 Design Basis for the Outdoor Storage Facility for Transuranic Intermediate-level Waste

Facilities for outdoor storage of TRU ILW are postulated for the four sites described in the introductory remarks to Section 5.3, with the exception of a facility at the MOX FFP. No ILW is generated at the MOX FFP; storage provisions are, therefore, not required there. The following assumptions apply to the design of the reference outdoor storage facilities:

- For outdoor storage at the fuel reprocessing plant - At full production the reference FRP generates TRU ILW at the rate of 8200 55-gal drums/yr (see Table 5.3.1 and Sections 4.3, 4.4, and 4.7). A storage capacity for about 32,800 55-gal drums is needed to accommodate TRU ILW generated during the first 5 years of FRP operation.
- For outdoor storage at an independent site - Interim storage of TRU ILW generated by all operating FRPs through 1990 (Case A) requires a capacity of 96,000 55-gal drums. Interim storage of such wastes generated through 1995 (Case B) requires a storage capacity of 184,000 55-gal drums. Case A and Case B are based on the assumed installation schedule for FRPs and reactors presented in Section 3.10.

5.3.3.3 Operations at the Outdoor Storage Facility for Transuranic Intermediate-level Waste

Figure 5.3.8 is an operations flow diagram for outdoor storage of TRU ILW. The waste is packaged into 55-gal drums at the FRP as described in Sections 4.3, 4.4, and 4.7. Drums of TRU ILW are transported to the storage site in multidrum shielded containers by a tractor and trailer combination. The tractor and trailer are moved over the top of the storage berm on the access road. A mobile yard crane is placed behind the trailer and a preselected vault is prepared by removing its shielding plug.

The drums are then moved from the shielded container to the hole by the crane, using a vacuum lifting device. The crane operator is protected from radiation by the shielded crane cab and distance attenuation. Other operators are protected by portable shields and distance. Existing safety regulations permit open air transfer of the waste, with administrative controls for waste packages with radiation levels up to 15 R/hr at contact.

Single drums with surface dose rates above 15 R/hr are transferred to the vaults through a bottom loading cask. Administrative controls require placing higher-activity drums at the bottom of the vault to ensure that skyshine will not cause undue radiation exposure while the shielding plug is off the vault. Each vault will contain 5 55-gal drums. Dessicant can be added to each vault after it is filled, though it may not be needed when storing waste in an arid region.

Waste retrieval is accomplished in the reverse manner. Shipment of the retrieved waste drums can be accomplished using a modified Super Tiger® shielded overpack container (see Section 6, Figure 6.6.1) in conjunction with a low-boy trailer.

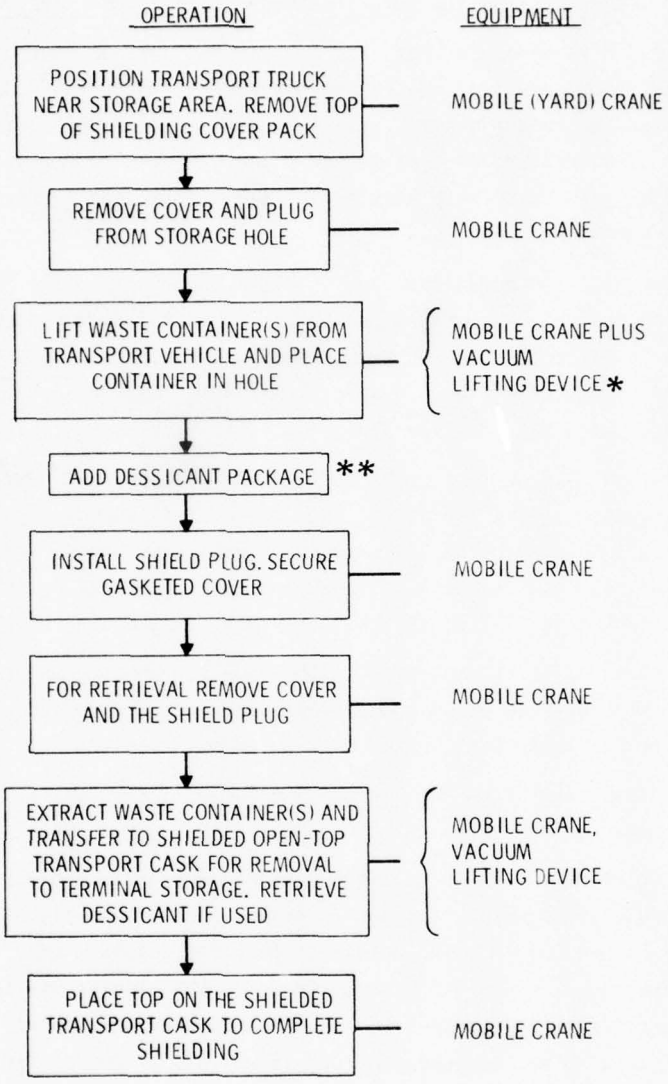
5.3.3.4 Description of the Outdoor Storage Facility for Transuranic Intermediate-level Waste

The basic storage module for outdoor storage of TRU ILW has a capacity of 2520 55-gal drums The basic module arrangement is shown in Figure 5.3.9. Details of an individual storage vault are shown in Figure 5.3.10. The reference facility consists of a berm 24 m (80 ft) wide, 160 m (524 ft) long, and 1.7 m (5.5 ft) high, in which 504 storage vaults are constructed. The berm is an engineered fill that slopes to the sides toward a peripheral drainage ditch, which carries water runoff to a retention pond. A road is built over the center of the berm for equipment access during drum burial operations.

Storage vaults are constructed by boring a hole 1 m (3.5 ft) in diameter and 5.5 m (18 ft) deep through the berm and the ground beneath it and inserting a 0.66 m (25-in.) diameter pipe assembly. Concrete grout is poured between the pipe assembly and the side wall of the hole to isolate the pipe and protect it from corrosion. A steel casing may be required to prevent the collapse of the hole during boring. Such casings are removed after the concrete is poured.

A plastic-lined retention pond is provided to collect runoff from the berm. Water collected is monitored for contamination and if found to be within permissible levels it is released through the surface drainage system. A personnel building, provided for the convenience of workers, is a light structural steel building 5 x 10 m (16 x 32 ft) that is insulated and weather-proofed. It contains an office, change room and washroom.

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* IN OPEN-AIR TRANSFERS OF TRU ILW, A SHIELDED HANDLING TRANSFER CASK MAY BE REQUIRED.

** WHERE EQUIPMENT IS NOT INDICATED THE OPERATION IS DONE MANUALLY. WHERE EQUIPMENT IS INDICATED THE OPERATION MAY BE DONE ENTIRELY WITH EQUIPMENT OR WITH A COMBINATION OF MANUAL AND EQUIPMENT OPERATIONS.

FIGURE 5.3.8. Operations Flow Diagram for the Outdoor Storage Facility for Transuranic Intermediate-level Waste

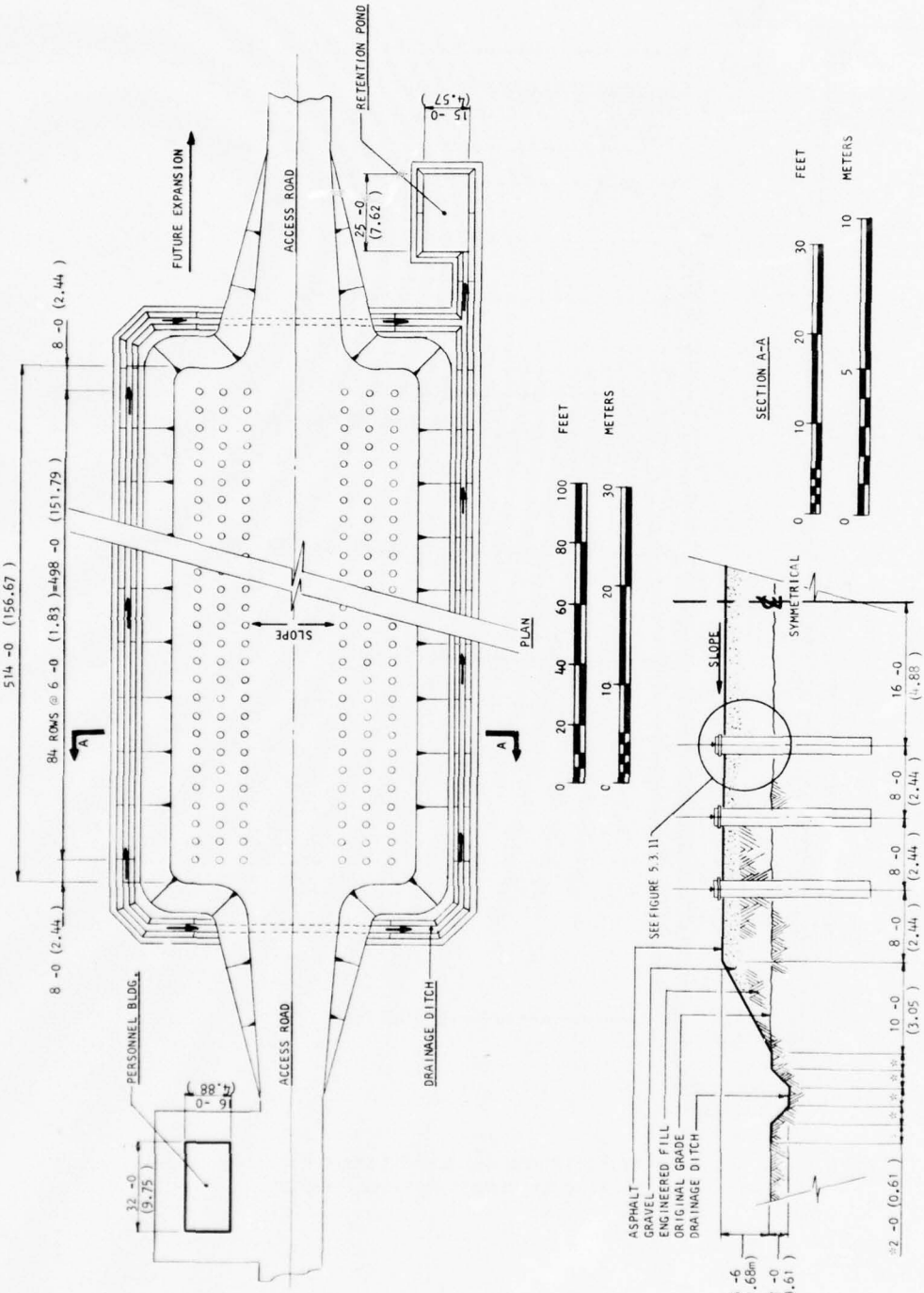


FIGURE 5.3.9. Outdoor Storage Facility for Transuranic Intermediate-level Waste, Basic Module Plan and Section A-A

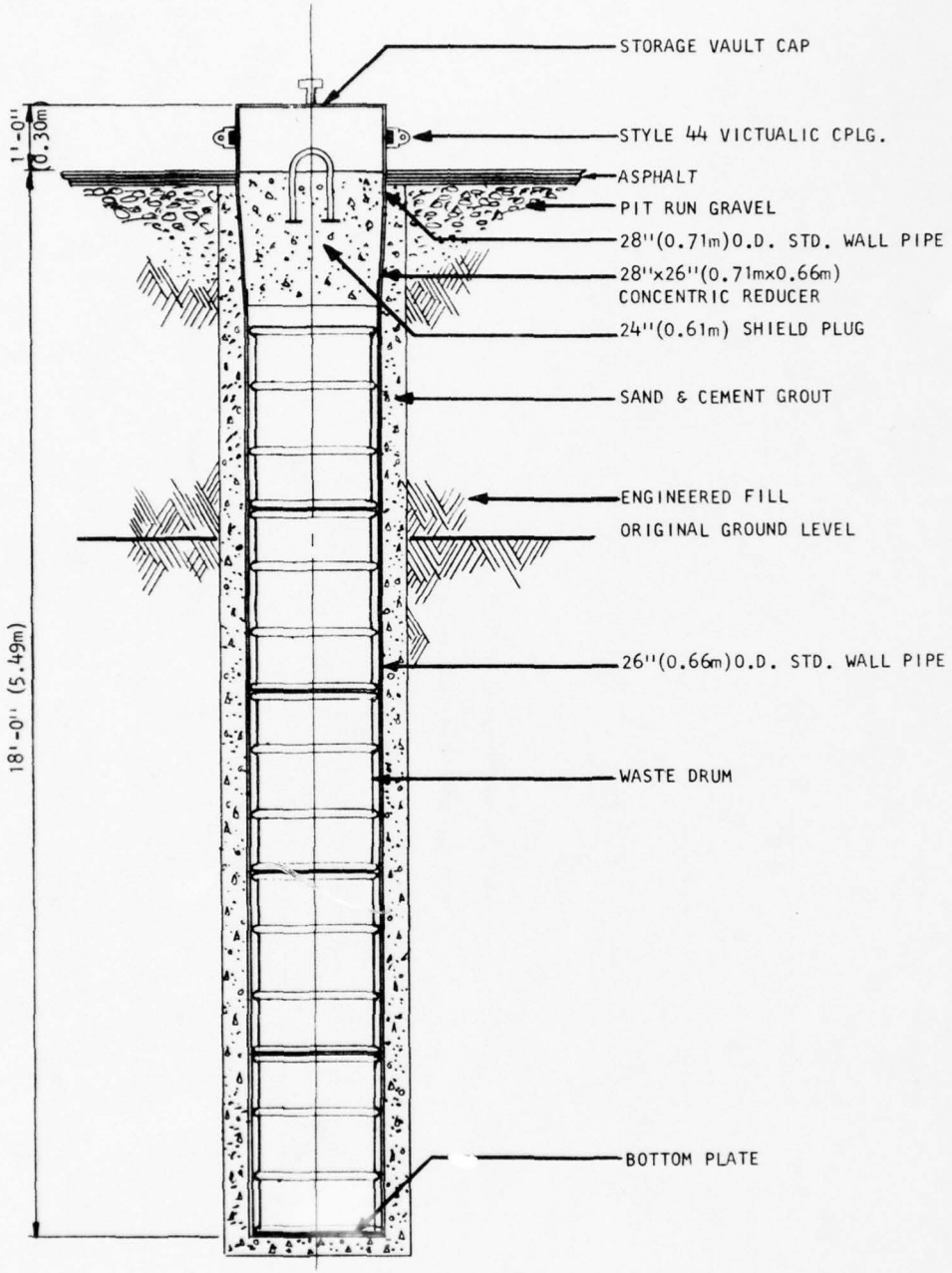


FIGURE 5.3.10. Storage Vault in the Outdoor Storage Facility for Transuranic Intermediate-level Waste

Major Equipment. For normal facility operations the following equipment is required:

- mobile yard crane
- multidrum shielded container
- single drum shielding cask
- tractor and trailer
- portable shield

Shielding and Remote Handling Equipment. Transuranic ILW must be handled remotely or shielding must be provided. Most of the drums containing TRU ILW have surface radiation readings well below 10 R/hr. Open air transfer of waste packages with radiation readings up to about 15 R/hr at contact (1 ft) would be permitted with strict administrative controls. Packages with radiation readings greater than 15 R/hr at contact would require the use of a shielded transfer cask. Packages with radiation readings of 15 R/hr or less would be transferred from the shielded overpack by remote methods. A crane with a shielded cab and an extended boom would be used to make the transfer. Operating personnel would keep sufficient distance between themselves and the package or use portable shields to keep radiation exposure well below the DOE-specified limits of 3 rem/quarter and 5 rem/yr. Transfers would be made in minutes so that exposures would be minimized. The radiation from a 15 R/hr (at 1 ft) package would be 0.01 R/hr at 50 ft. At 100 ft, the radiation level would be 1.5×10^{-3} R/hr. At 1000 ft, the exposure rate would be 1.5×10^{-5} R/hr. At distances greater than 1000 ft the exposure rate during transfers approaches background levels. Therefore, there would be no general population exposures as a result of these operations.

5.3.3.5 Operating and Maintenance Requirements for the Outdoor Storage Facility for Transuranic Intermediate-level Waste

In the FRP outdoor facility for storage of ILW, the required number of drums can be placed in storage in one 8-hr shift per day. A crew of two operators and one radiation monitor is used to place drums in storage. Two shifts a day may be required for the independent facility when 55 and 77 drums/day, for Case A and B respectively, are placed in storage.

Staffing. Personnel requirements for outdoor storage of TRU ILW at the FRP and at the independent sites in 1990 and 1995 are given in Table 5.3.19.

TABLE 5.3.19. Staffing Requirements for Outdoor Storage of Transuranic Intermediate-level Waste

	Personnel Required, man-yr/yr		
		Independent Site	
Job Description	FRP	Case A(a)	Case B(b)
Operators	2	5	7
Radiation monitors	1	2.5	3.5
Maintenance craftsmen	0.2	0.6	1

a. For storing wastes generated through 1990.
b. For storing wastes generated through 1995.

Supplies and Utilities. Estimated supplies and utilities for the reference facility at peak handling periods are given in Table 5.3.20.

TABLE 5.3.20. Supplies and Utilities for Outdoor Storage of Transuranic Intermediate-level Waste

Item	Use Rate	Annual Requirement		
		FRP	Independent Site Case A(a)	Independent Site Case B(b)
Electricity	100 kW	70 MW-hr	300 MW-hr	400 MW-hr
Diesel fuel	23 ℓ/hr	23,000 ℓ	38,000 ℓ	53,000 ℓ
Dessicant	10 kg/hr	7,400 kg	12,000 kg	17,000 kg

a. For storing wastes generated through 1990.
b. For storing wastes generated through 1995.

5.3.3.6 Secondary Radioactive Wastes for the Outdoor Storage Facility for Transuranic Intermediate-level Waste

No secondary radioactive wastes are generated from routine operation of these facilities.

5.3.3.7 Emissions from the Outdoor Storage Facility for Transuranic Intermediate-level Waste

No chronic emissions are expected from routine operation of these facilities.

5.3.3.8 Decommissioning Considerations for the Outdoor Storage Facility for Transuranic Intermediate-level Waste

The outdoor subsurface storage facilities are designed for the interim storage of TRU ILW for up to a 10 to 15 yr period, followed by a similar period for transfer of the stored waste to a final repository. After removal of the stored waste, the facilities will be free of radioactive contamination and available for routine salvage procedures.

5.3.3.9 Postulated Accidents for the Outdoor Storage Facility for Transuranic Intermediate-level Waste

The minor accidents postulated for the reference facility are the same as those presented in Table 5.3.4. Consult Table 5.3.1 for the inventories of the ILW drums.

The release from moderate accident 5.3.8 (Crane Drops Drum) in Table 5.3.21 was selected as an umbrella source term. (See Section 3.7 for a description of umbrella accidents and Appendix 3A for a cross index listing of accidents and umbrella accidents by accident numbers.) In this accident it was estimated that no more than 1% of drum contents would be released from the shielded handling cask. Air entrainment was assumed to disperse 0.5% of the exposed material for an overall release fraction of 5×10^{-5}.

No accidents that could be classified as severe accidents could be realistically postulated for this technology.

TABLE 5.3.21. Moderate Accidents for Outdoor Storage of Transuranic Intermediate-level Waste

Accident No. and Description	Sequence of Events	Safety System	Release
5.3.8 — Crane drops drum.	1. Drum secured to vacuum lift for transfer to storage. 2. Drum lifted from shielded transporter. 3. Vacuum lift fails, releasing drum. 4. Drum breached on impact with pad. 5. Cleanup and repackaging initiated and completed.	1. Double-hold device on vacuum lift. 2. Drums designed to survive drop of 9 m when filled with 200 kg water. 3. Lift height restricted to less than 4.4 m.	A release fraction for the failed drum and shielded overpack was estimated to be 5×10^{-5} to the atmosphere at ground level. Table 5.3.1 describes the contents of ILW drums.

5.3.3.10 Costs for the Outdoor Storage Facility for Transuranic Intermediate-level Waste

Estimates have been made, in mid-1976 dollars, of capital, operating, and levelized unit costs for outdoor storage of TRU ILW at the FRP and at an independent site. A description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Cost. Capital costs for outdoor storage facilities at the FRP and an independent site are determined from the initial cost of the basic module and from the costs for building additional storage modules. Table 5.3.22 gives the capital cost estimate for the basic module used at the FRP. The estimate covers all capital costs associated with incorporating this module into the FRP described in Section 3.2. These costs also include the effect of additions to the common facilities, such as the electrical substation, shops, and compressed air facilities attributable to the basic module. General FRP costs for such services as laboratories and warehousing, however, have not been allocated to the reference storage facility. The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of operations with the exception of working capital.

Since the outdoor storage facility for TRU ILW at an independent site is not an integral part of another facility with which it can share support services, the capital cost of providing such services must be added to the estimate given in Table 5.3.22 in order to obtain the total capital cost of constructing the basic outdoor storage module at an independent site. Table 5.3.8 gives the incremental capital cost estimate for support services for an independent storage facility.

The accuracy range for these estimates reflects uncertainties in the engineering scope required to provide a fully functional facility based on the technology described and in the pricing and quantities for labor, materials, and equipment. A contingency covering these and similar factors has been included in the base estimate.

Capital costs for building additional storage modules are shown in Table 5.3.23. Once a basic module has been built, other modules may be added to increase storage capacity without incurring the one-time expenses, such as electrical substation, personnel building, shops,

compressed air, and equipment. However, there is only a small cost scaling advantage for larger facilities in this case. For example, a ten fold expansion of the basic module costs approximately nine times more.

TABLE 5.3.22. Capital Cost Estimate for the Basic Outdoor Storage Module for Transuranic Intermediate-level Waste

Cost Element	Man-hours, 1000s		Costs, 1000s Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major Equipment		3	195	35	238
Buildings and structures		20	1465	240	1705
Bulk materials					
Site improvements					
Subtotal of direct site construction costs		23	1660	275	1935
Indirect site construction costs	6	5	100	135	235
Total field cost	6	28	1760	410	2170
Architect-engineer services					390
Subtotal					2560
Owner's cost					740
Total facility cost					3300
Estimate accuracy range					±30%

TABLE 5.3.23. Capital Cost Estimate for Incremental Expansion of Basic Outdoor Storage Module for Transuranic Intermediate-level Wastes

Number of Modules	Total Capacity, Number of 55-gal Drums	Total Capital Costs, 1000s
1	2,520	3,300
2	5,040	6,200
4	10,080	12,000
6	15,120	17,800
8	20,160	23,600
12	30,240	35,200
34	85,680	99,000
65	163,800	188,900

As stated earlier (Section 5.3.3.2), the reference outdoor storage facility for TRU ILW at the FRP requires a capacity of 32,800 55-gal drums to accommodate all the TRU ILW generated during the first 5 years of FRP operation. This capacity would be provided as needed over the 5-year period by building additional basic storage modules, each with a capacity of 2520 55-gal drums. Table 5.3.24 gives the capital cost schedule for the reference storage facility at the FRP, as well as the schedule for capacity expansion.

Capacity at an independent facility is assumed to be provided as needed to accommodate TRU ILW generated by all operating FRPs. The capital cost schedule for expanding the independent facility is shown in Table 5.3.25. This table also shows the schedule for capacity expansion and incorporates the incremental cost for support services as given in Table 5.3.8.

TABLE 5.3.24. Capital Cost Schedule for the Outdoor Storage Facility for Transuranic Intermediate-level Wastes at the Fuel Reprocessing Plant

Year After Startup	Capacity Expansion, Number of 55-gal Drums	Capital Cost Increase, $1000s
0	5,040	6,200
1	5,040	5,800
2	7,560	8,700
3	7,560	8,700
4	7,600	8,700
Total	32,800	38,100

TABLE 5.3.25. Capital Cost Schedule for Expanding the Capacity for Outdoor Storage of Transuranic Intermediate-level Waste at an Independent Site

	Capacity Expansion, Number of 55-gal Drums		Capital Cost Increase, $1000s	
Year	Case A(a)	Case B(b)	Case A(a)	Case B(b)
1981	2,520	2,520	4,900	4,900
1982	5,040	5,040	5,800	5,800
1983	5,040	5,040	5,800	5,800
1984	7,560	7,560	8,700	8,700
1985	7,560	7,560	8,700	8,700
1986	12,600	12,600	14,500	14,500
1987	12,600	12,600	14,500	14,500
1988	15,120	15,120	17,400	17,400
1989	15,120	15,120	17,400	17,400
1990	12,840	12,600	14,800	14,500
1991	-	15,120	-	17,400
1992	-	15,210	-	17,400
1993	-	15,120	-	17,400
1994	-	20,160	-	23,200
1995	-	22,720	-	26,600
Total	96,000	184,000	112,500	214,200

a. For storing wastes generated through 1990.
b. For storing wastes generated through 1995.

Operating Costs. The operating cost components for outdoor storage of TRU ILW are shown in Table 5.3.26. Direct labor costs are based on manpower estimates given in Table 5.3.19. Process material and utility costs are derived from requirements shown in Table 5.3.20. Annual maintenance materials costs are estimated at 3% of initial major equipment costs. Overhead and miscellaneous costs are estimated using the standard method described in Section 3.8. The estimates for the miscellaneous items are intended to include all unidentified operating costs. The cost of taxes, insurance, and interest are included in the capital charge segment of the levelized unit cost.

TABLE 5.3.26. Operating Cost Estimate for Outdoor Storage of Transuranic Intermediate-level Waste

	Annual Costs, $1000s		
		Independent Site	
Cost Element	FRP	Case A[a]	Case B[b]
Direct labor	50	180	180
Process materials	0	0	0
Utilities	5	10	15
Maintenance materials	15	25	25
Overhead	60	200	200
Miscellaneous	30	55	60
Total	160 +50% -25%	470 +50% -25%	480 +50% -25%

a. For storing wastes generated through 1990.
b. For storing wastes generated through 1995.

Operating costs for the storage facility at the FRP are based on waste quantities accumulated from 5 years of FRP operation. Operating costs for the independent facilities are based on waste quantities accumulated from all FRPs through 1990 (Case A) and 1995 (Case B), respectively.

Levelized Unit Costs. Table 5.3.27 lists the total levelized unit costs as well as the levelized capital and operating components. The cost calculations assume private ownership of the facility at the FRP and Federal ownership at the independent site. Calculations also assume a 15-year economic life. Capital costs for facility expansions at the independent site are assumed to be expended according to the schedule in Table 5.3.25.

TABLE 5.3.27. Levelized Unit Cost Estimate for Outdoor Storage of Transuranic Intermediate-level Waste

	Unit Cost, $/kgHM		
		Independent Site	
Cost Element	FRP	Case A(a)	Case B(b)
Levelized capital charge	7.60	4.80	4.70
Levelized operating charge	0.30	0.30	0.30
Levelized total unit cost	7.90 ±30%	5.10 ±30%	5.00 ±30%

a. For storing wastes generated through 1990.
b. For storing wastes generated through 1995.

5.3.3.11 Construction Requirements for the Outdoor Storage Facility for Transuranic Intermediate-level Waste

Many factors related to site preparation and reference facility construction for the basic module may have some impact on the environment, the local economy, and natural resources of the surrounding area. Except where specified, the information given in this section is for the outdoor storage facility basic storage module and assumes that the basic module for TRU ILW is integrated into the original design and construction of the fuel reprocessing plant. Requirements for facilities that incorporate expansions of the basic module may be approximated by linear extrapolation according to facility capacity.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of the basic module is an integral factor in the overall schedule for the design and construction of the FRP. The field labor force estimated for module construction is as follows:

	Man-hours, 1000s
Manual field labor	28
Nonmanual field labor	6
Total field labor	34

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is shown below:

	Costs, 1000s
Onsite	500
Offsite	2800
Total	3300

Site Requirements. Outdoor storage of TRU ILW requires about 7.7 ha (19 acres) within the FRP site for the total requirement of 13 modules. This is about seven times the area designated for solid non-high level waste storage within the reference FRP site (33 in Figure 5.3.1). The exclusion fence would have to be extended to accommodate this concept.

The independent site would preferably be located near a potential site for the final repository. Land requirements for an independent site are estimated to be 20 ha (50 acres) for the 34 modules required for storing wastes generated through 1990 and 38 ha (95 acres) for the 65 modules required for storing wastes generated through 1995.

Water. Approximately 380 m^3 (1×10^5 gal) of water are required during the construction period.

Construction Materials. Materials committed to basic module construction are:

Concrete	380 m^3	(500 yd^3)
Steel	540 MT	(600 tons)
Lead	12 MT	(13 tons)
Lumber	50 m^3	(20 MFBM)

Energy. Energy resources used during construction are:

Propane	4 m^3	(1,000 gal)
Diesel fuel	38 m^3	(10,000 gal)
Gasoline	27 m^3	(7,000 gal)
Electricity		
Peak demand		40 kW
Total consumption		20,000 kWh

Transportation Requirements. No transportation requirements for the outdoor storage facility for TRU ILW are identified beyond those for the reference FRP. A two-lane road to a public highway is required for an independent facility.

5.3.3.12 Effects of Fuel Cycle Options

Impacts of alternative fuel cycles are identical to those presented in Section 5.3.12.

5.3.4 Indoor Shielded Storage of Transuranic Intermediate-level Waste

Indoor shielded storage of ILW is an alternative to outdoor below-grade storage. The concept calls for the construction of heavily shielded storage vaults. Remote handling equipment is necessary for the placement of the ILW. Due to the possibility of high dose rates, the concept requires remote operation. There is no commercial experience in storing ILW in this manner and only limited experience at government facilities.

5.3.4.1 Alternative Indoor Storage Concepts for Transuranic Intermediate-level Waste

The high cost of shielded waste containers generally dictates that TRU ILW be packaged in unshielded containers. In this case, shielding during storage can be provided one of two ways. First, the storage building can be constructed to serve as shielding for the waste; a thick-walled, cast-in-place concrete structure would be practical for this purpose. One concept of this type involves a building with a number of cells for storing the waste. Waste is delivered in a shielded cask and is placed outside a preselected cell. Waste drums are placed in the cell via a remotely controlled bridge crane which can later be used to retrieve them. Within the cell, waste packages are handled remotely.

The second alternative for storing intermediate-level transuranic wastes packaged in unshielded containers is to provide permanent, shielded containment, such as concrete pipes, holes in the ground, or trenches, within the storage building. Openings into the shielded

containment are designed to fit the shipping cask so that the waste containers can be transferred from the cask without exposing operating personnel to radiation. With this shielded containment concept, the storage building itself would serve primarily as a shelter to facilitate storage and retrieval operations during adverse weather.

Comparing these two concepts, the shielded storage building concept offers the following advantages:

- The remote handling techniques required in such a facility offer greater protection against radiation hazards.
- It permits remote inspection of the waste containers during storage.
- It provides greater versatility in accommodating waste packages of various sizes and shapes.
- It enables more efficient use of the storage space provided.

In light of these advantages, a shielded storage building was selected as the reference indoor storage concept for TRU ILW.

5.3.4.2 Design Basis for the Indoor Storage Facility for Transuranic Intermediate-level Waste

The design basis for the indoor storage facility for TRU ILW is the same as that presented in Section 5.3.3.2 for outdoor storage of the same wastes.

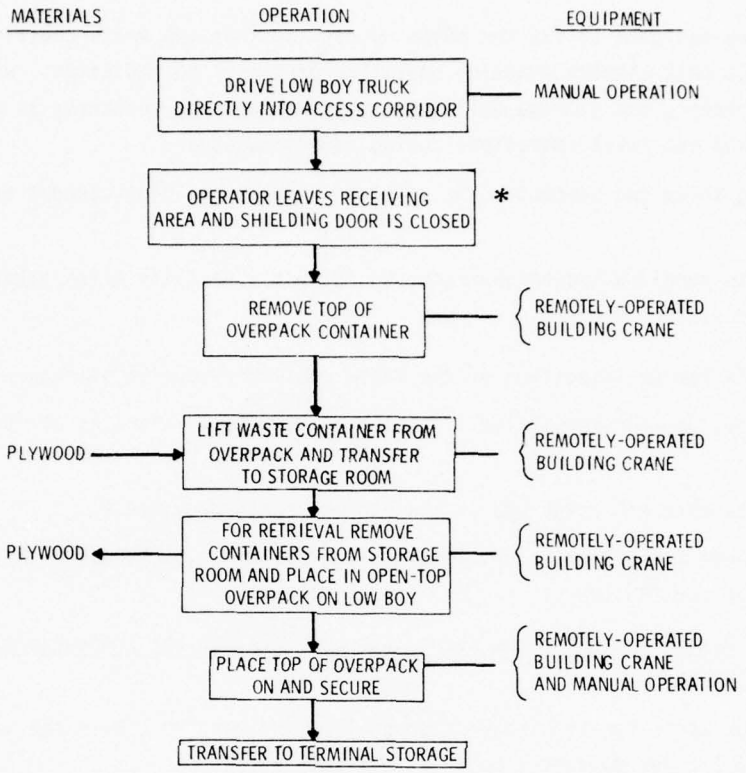
5.3.4.3 Operations at the Indoor Storage Facility for Transuranic Intermediate-level Waste

Storage and retrieval operations at the indoor shielded storage facility are shown in Figure 5.3.11. Materials and equipment used in the operations are also listed.

Drums of TRU ILW arrive at the waste receiving area in a multidrum, shielded container carried by a low boy truck or a tractor-trailer combination. Drums with very high radiation levels may be transported in single-drum shielded casks. Once the trailer is inside the storage building and operating personnel have left the receiving area, the exterior shielding door is closed. The drums are then remotely unloaded from the container or cask by the following operations:

- The drum container is opened.
- The shielding gates at the roof are opened.
- The crane is positioned directly above the drums.
- The drums are lifted from the container.

To permit quick unloading, a drum surge area is provided at the upper level directly above the control room so that about 90 drums may accumulate. The 10-ton bridge crane is remotely operated from the control room, which contains television monitors. The crane runs



*WHERE EQUIPMENT IS NOT INDICATED THE OPERATION IS DONE MANUALLY. WHERE EQUIPMENT IS INDICATED THE OPERATION MAY BE DONE ENTIRELY WITH EQUIPMENT OR WITH A COMBINATION OF MANUAL AND EQUIPMENT OPERATIONS.

FIGURE 5.3.11. Operations Flow Diagram for Indoor Storage of Transuranic Intermediate-level Waste

over the entire length of the storage area and transports the drums using a vacuum-operated lifting device. Positioning, viewing and unloading of drums is aided by two TV cameras (with pan, tilt and zoom lenses) carried by the crane at bridge level, and by spotlights that illuminate the entire work area. When maintenance work is required on the crane, it can be moved to the crane maintenance area, which is separated from the storage area by a guillotine-type shielding door.

Five layers of drums, 100 drums to the layer, are placed in each cell. Each layer is separated by sheets of 1.27-cm plywood.

Operations are reversed for retrieval of waste packages for shipment to a final repository. Storage and retrieval operations are the same for facilities at the FRP and at an independent site.

5.3.4.4 Description of the Indoor Storage Facility for Transuranic Intermediate-level Waste

The basic storage module for indoor storage of TRU ILW is a Category I structure and has a capacity of 20,000 drums (40 cells, 500 drums/cell). The general arrangement and section views of the basic module are shown in Figures 5.3.12 and 5.3.13. The module has two main operating areas: 1) the service area, which comprises the drum receiving room, control room and offices; and 2) the storage area, which comprises a series of adjacent twin cells separated by structural partitions. The storage portion of each cell is 6.1 m (20 ft) square and 5.2 m (17 ft) high. An additional 3.7 m (12 ft) above the cells is needed for crane operation. The cell walls are 0.91 m (3 ft) thick and have unpainted interior surfaces smoothly finished with a sealant compound. Floors and ceilings are similarly treated. Permanent lighting is not required in the cells since the crane carries the necessary lighting and viewing equipment. Air circulation through the storage area is provided by ventilation openings located in the roof and walls of each cell.

Major Equipment. For operation of the indoor storage facility the following equipment is required:

- 10-ton bridge crane
- multi-drum shielded container
- single drum shielding cask
- tractor and trailer.

Shielding and Remote Handling Equipment. The reference storage facility for TRU ILW provides the necessary shielding for the stored wastes. Waste drums are handled by the remotely operated 10-ton bridge crane.

5.3.4.5 Operating and Maintenance Requirements for the Indoor Storage Facility for Transuranic Intermediate-level Waste

In the reference FRP indoor storage facility for TRU ILW, the required number of drums can be placed in storage in one 8-hr shift per day. Two shifts per day may be required for the independent facility when 55 and 77 drums per day, for Case A and Case B respectively, are placed in storage.

No unusual maintenance procedures are expected for the reference facility. The 10-ton bridge crane is maintained in an area shielded by a guillotine-type shielding door.

Staffing. Personnel requirements for indoor shielded storage of TRU ILW are the same as those given for outdoor subsurface storage in Table 5.3.19.

Supplies and Utilities. Estimated supplies and utilities for indoor shielded storage at peak handling periods are given in Table 5.3.28.

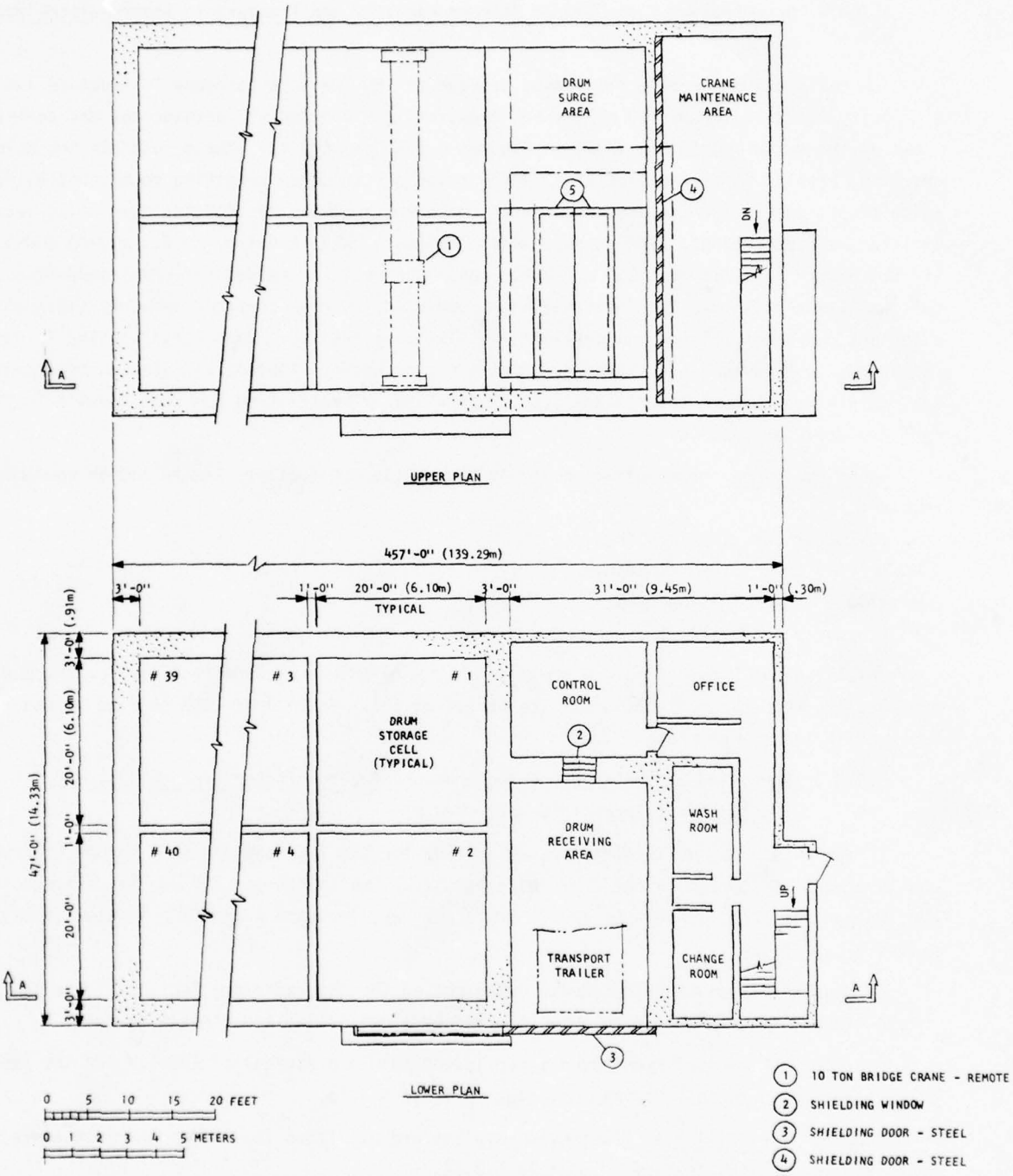


FIGURE 5.3.12. Indoor Storage Facility for Transuranic Intermediate-level Waste, General Plan

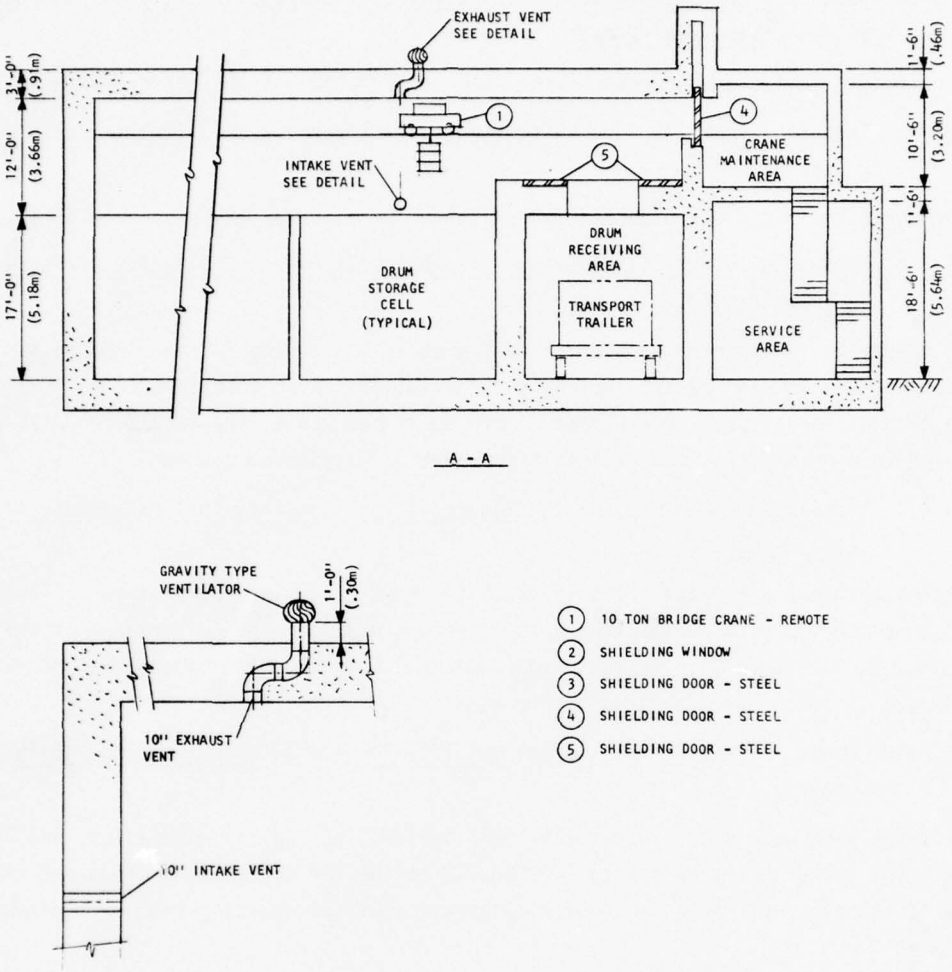


FIGURE 5.3.13. Indoor Storage Facility for Transuranic Intermediate-level Waste, Section A-A

TABLE 5.3.28. Supplies and Utilities for Indoor Storage of Transuranic Intermediate-level Waste

Item	Use Rate	Annual Requirement		
			Independent Site	
		FRP	Case A[a]	Case B[b]
Electricity	200 kW	200 MW-hr	350 MW-hr	500 MW-hr
Diesel fuel	11 ℓ/hr	11,000 ℓ	19,000 ℓ	26,500 ℓ
Plywood, 1.27 cm	6 m^2/hr	2,400 m^2	4,200 m^2	5,700 m^2

a. For storing waste generated through 1990.
b. For storing waste generated through 1995.

5.3.4.6 Secondary Radioactive Wastes for the Indoor Storage Facility for Transuranic Intermediate-level Waste

No secondary wastes are generated from routine operation of the reference facility.

5.3.4.7 Emissions from the Indoor Storage Facility for Transuranic Intermediate-level Waste

No chronic emissions are expected from routine operation of the reference facility.

5.3.4.8 Decommissioning Considerations for Indoor Storage Facility for Transuranic Intermediate-level Waste

The reference indoor storage facilities are designed for the interim storage of TRU ILW for up to a 10- to 15-year period, followed by a similar period for transfer of the stored drums to a final repository. After removal of the stored waste, the facilities will be free of radioactive contamination and available for routine salvage procedures.

5.3.4.9 Postulated Accidents for the Indoor Storage Facility for Transuranic Intermediate-level Waste

Postulated minor accidents for this facility are the same as those given in Table 5.3.4, as well as Accident 5.3.7 from Table 5.3.13. The postulated moderate accident is the same as Accident 5.3.8, Table 5.3.21. No accidents that could be classified as severe accidents could be realistically postulated for this technology.

5.3.4.10 Costs for the Indoor Storage Facility for Transuranic Intermediate-level Waste

Estimates have been made, in mid-year 1976 dollars, of capital, operating, and levelized unit costs for indoor shielded storage of TRU ILW at the FRP and at an independent site. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Cost. Capital costs for facilities for indoor storage of ILW at the FRP and an independent site are determined from the initial cost of the basic module and from the cost for additional storage modules. The capital cost estimate for the basic indoor storage module is shown in Table 5.3.29. The estimate covers all capital costs associated with incorporating the basic module into the reference FRP. These costs also include the costs of additions to the common facilities attributable to the basic module, such as electrical supply from the substation, steam, water and compressed air, as well as bulk materials for piping, electrical, and instrument tie-ins with the FRP. However, general FRP costs for such services as laboratories, personnel facilities, health physics support, warehousing, and shops are not allocated to the reference storage facility. The total capital cost includes all facility-related costs incurred from the start of engineering to the initiation of storage operations with the exception of working capital.

TABLE 5.3.29. Capital Cost Estimate for the Basic Indoor Storage Module for Transuranic Intermediate-level Waste

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		2	1,040	20	1,060
Buildings and structures		218	1,360	2,580	3,940
Bulk materials					
Site improvements					
Subtotal of direct site construction costs		220	2,400	2,600	5,000
Indirect site construction costs	60	40	900	1,300	2,200
Total field cost	60	260	3,300	3,900	7,200
Architect-engineer services					1,300
Subtotal					8,500
Owner's cost					2,500
Total facility cost					11,000
Estimate accuracy range					±25%

Since the indoor storage facility at an independent site is not an integral part of another facility with which it can share support services, the capital cost of providing such services must be added to the estimate given in Table 5.3.29 in order to obtain the total capital cost of constructing the basic indoor storage module at an independent site. Table 5.3.8 gives the incremental capital cost estimate for support services for an independent storage facility.

The accuracy range of these estimates reflects uncertainties in the engineering scope required to provide a fully functional facility based on the technology described and in the pricing and quantities for labor, materials, and equipment. A contingency covering these and similar factors has been included in each of the base estimates.

Capital costs for building additional storage modules are shown in Table 5.3.30. Once a basic module has been built, other modules may be added to increase storage capacity without incurring one-time expenses for auxiliaries such as the electrical substation, personnel building, shops, compressed air, and equipment. This results in a small cost scaling advantage for larger facilities. For example, an eight fold expansion of the basic storage module costs approximately 6 1/2 times more.

As stated earlier (Section 5.3.4.2), the reference indoor storage facility for TRU ILW at the FRP requires a capacity of 32,800 55-gal drums to accommodate all the TRU ILW generated during the first 5 years of FRP operation. This capacity would be provided by adding a 12,800 drum unit to the basic module 3 years after start up. Table 5.3.31 gives the total capital cost schedule for the reference storage facility at the FRP, showing the schedule and the incremental costs for capacity expansion.

TABLE 5.3.30. Capital Cost Estimate for Adding Basic Modules to Indoor Storage Facilities for Transuranic Intermediate-level Waste

Number of Modules	Total Capacity, Number of 55-gal Drums	Total Capital Cost, $1000s
1	20,000	11,000
2	40,000	19,200
3	60,000	27,400
4	80,000	35,600
5	100,000	46,600[a]
6	120,000	54,800
7	140,000	63,000
8	160,000	71,200

a. On the fifth expansion, a new head end structure is required.

TABLE 5.3.31. Capital Cost Schedule for Indoor Storage of Transuranic Intermediate-level Waste at the Fuel Reprocessing Plant

Years After Startup	Capacity Expansion, Number of 55-gal Drums	Capital Cost Increase, $1000s
0	20,000	11,000
3	12,800	5,200
Total	32,800	16,200

The capital costs for expanding the capacity of the independent facility to store TRU ILW generated through 1990 and 1995 are shown in Table 5.3.32. This table also gives the schedule for capacity expansion and incorporates the incremental cost for support services given in Table 5.3.8.

Operating Costs. The operating cost components for indoor storage of TRU ILW are shown in Table 5.3.33. Direct labor costs are based on manpower estimates given in Table 5.3.19. Process material and utility costs are derived from requirements shown in Table 5.3.28. Annual maintenance materials costs are estimated at 3% of initial major equipment costs. Overhead and miscellaneous costs are estimated using the standard methods described in Section 3.8. The estimates for the miscellaneous items are intended to include all unidentified operating costs. The cost of taxes, insurance, and interest are included in the capital charge segment of the levelized unit cost.

Operating costs for the FRP storage facility are based on waste quantities accumulated from 5 years of FRP operation. Operating costs for the independent facilities are based on waste quantities accumulated from all FRPs through the year 1990 (Case A) and 2000 (Case B).

TABLE 5.3.32. Capital Cost Schedule for Expanding the Capacity for Indoor Storage of Transuranic Intermediate-level Waste at an Independent Site

Year	Capacity Expansion, Number of 55-gal Drums		Capital Cost Increase, $1000s	
	Case A(a)	Case B(b)	Case A(a)	Case B(b)
1981	20,000	20,000	12,600	12,600
1985	20,000	20,000	8,200	8,200
1987	20,000	20,000	8,200	8,200
1988	20,000	20,000	8,200	8,200
1989	16,000	20,000	9,700	11,000(c)
1991		20,000		8,200
1992		20,000		8,200
1993		20,000		8,200
1994		20,000		8,200
1995		4,000		2,300
Total	96,000	184,000	46,900	83,300

a. For storing wastes generated through 1990.
b. For storing wastes generated through 1995.
c. On the fifth expansion, a new head end structure is required.

TABLE 5.3.33. Operating Cost Estimate for Indoor Shielded Storage of Transuranic Intermediate-level Waste

Cost Element	Annual Costs, $1000s					
			Independent Site			
	FRP		Case A(a)		Case B(b)	
Direct labor	50		180		180	
Process materials	5		7		10	
Utilities	5		10		13	
Maintenance materials	10		13		15	
Overhead	55		200		200	
Miscellaneous	15		20		22	
Total	140	+50% -25%	430	+50% -25%	440	+50% -25%

a. For storing wastes generated through 1990.
b. For storing wastes generated through 1995.

Levelized Unit Costs. Table 5.3.34 lists the total levelized unit cost as well as the levelized capital and operating components. The cost calculations assume private ownership of the facility at the FRP and Federal ownership at the independent site. Calculations also assume a 15-yr economic life. Capital costs for facility expansions at the independent site are assumed to be expended according to the Schedule in Table 5.3.32. This storage method costs only about half as much as the outdoor concept.

TABLE 5.3.34. Levelized Unit Cost Estimate for Indoor Shielded Storage of Transuranic Intermediate-level Waste

Cost Element	Unit Cost, $/kgHM		
		Independent Site	
	FRP	Case A(a)	Case B(b)
Levelized capital charge	4.20	2.10	2.00
Levelized operating charge	0.20	0.20	0.20
Levelized total unit cost	4.40 ±30%	2.30 ±25%	2.20 ±25%

a. For storing wastes generated through 1990.
b. For storing wastes generated through 1995.

5.3.4.11 Construction Requirements for the Indoor Storage Facility for Transuranic Intermediate-level Waste

Many factors related to site preparation and facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information in this section is for the indoor storage facility basic module, and assumes that the basic module is integrated into the original design and construction of the reference FRP. Requirements for facilities that incorporate expansions of the basic module may be approximated by linear extrapolation according to capacity.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of the indoor shielded storage basic module is an integral factor in the overall project schedule for the FRP. The field labor force estimated for the construction of the basic module is tabulated below:

	Man-hours, 1000s
Manual field labor	260
Nonmanual field labor	60
Total field labor	320

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the FRP, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is shown below:

	Costs, $1000s
Onsite	4,000
Offsite	7,000
Total	11,000

Site Requirements. Indoor storage of TRU ILW requires about 0.32 ha (0.8 acres) within the reference FRP site. Location is shown in Figure 5.3.1. The independent site would preferably be located near the potential site of the final repository. Land requirements are

estimated to be about 0.8 ha (2 acres) for an independent facility for storing TRU ILW generated through 1990 (Case A) and 1.6 ha (4 acres) for storing wastes generated through 1995 (Case B).

Water. Approximately 4900 m^3 (1.3 x 10^6 gal) of water are required during the construction period.

Construction Materials. Materials committed to basic module construction are:

Concrete	5,700 m^3	(7,400 yd^3)
Steel	900 MT	(1,000 tons)
Lead	12 MT	(13 tons)
Lumber	350 m^3	(150 MFBM)

Energy. Energy resources used during construction are:

Propane	38 m^3	(10,000 gal)
Diesel fuel	380 m^3	(100,000 gal)
Gasoline	246 m^3	(65,000 gal)
Electricity		
Peak demand	400 kWh	
Total consumption	180,000 kWh	

Transportation Requirements. No separate transportation requirements for the indoor storage facilities for TRU ILW have been identified beyond those for the reference FRP. A two-lane paved road to a public highway is required for an independent site.

5.3.4.12 Effects of Fuel Cycle Options

Impacts of alternative fuel cycles on the reference storage concept are identical to those presented in Section 5.3.1.12.

5.3.5 Physical Protection and Safeguard Requirements for Non-high-level Waste Storage

Non-high-level wastes are not attractive targets for theft or sabotage because of the very low average quantities of plutonium and the variable amounts of fission products present. The wastes would contain radioactive materials in concentrations several orders of magnitude below those in spent fuel, many would be immobilized in concrete (or alternatively in bitumen), and would be packaged in 55-gal drums or large boxes. The variations in fission product content would result in surface dose rates that are expected to vary from below 0.2 R/hr to above 10 R/hr.

A sabotage event or threat would create concerns over releases estimated to be not greater than those described in Accident 5.3.1. While sabotage could potentially result in some releases to the atmosphere, the amounts would result in no significant health threats to the public. Should a sabotage act result in a fire involving the bitumen, the consequences described in Accident 4.7.6 are adequate to describe the consequences. In that event, 1% of one kg of the

fixed waste would be released to the cell or the vault or burial crypt atmosphere, with lesser amounts being released to the environment. Though an attempted sabotage of non-high-level waste storage that results in a fire is of serious concern, its consequences to the public are small.

The overall physical security required at sites containing non-high-level wastes is available to protect the public from willful misuse of this waste.

REFERENCES FOR SECTION 5.3

1. Alternatives for Managing Wastes from Reactors and Post-Fission Operations in the LWR Fuel Cycle. ERDA-76-43, Energy Research and Development Administration, Washington, DC, May 1976.

5.4 SOLIDIFIED HIGH-LEVEL WASTE STORAGE

5.4 SOLIDIFIED HIGH-LEVEL WASTE STORAGE

Solidified high-level waste (SHLW) is generated by conversion of high-level liquid waste (HLLW) to a stable solid form. The solidified waste is packaged in sealed metal canisters, which are inspected, stored for an interim period at the fuel reprocessing plant (FRP), then shipped to a geologic repository for terminal isolation. Until geologic repositories are available, additional interim storage at a Federal storage site may be required. Methods for packaged SHLW interim storage at the FRP and at an independent government operated site are discussed in this section.

At DOE's Idaho Chemical Processing Plant, HLLW is calcined to a solid then stored in underground bins. During the Waste Solidification Engineering Prototype (WSEP) development program at the Pacific Northwest Laboratory, 33 packages of SHLW were generated and are currently being stored in both air and water for waste characterization and storage studies. There is also experience in France with air storage of packaged industrial SHLW.

A variety of facilities studied for storage of SHLW[1,2] are compared in Table 5.4.1. The concepts may be divided into two categories: 1) dynamic storage systems where mechanical devices are used for heat dissipation, such as the water basin, and 2) passive storage systems where no mechanical devices are needed, such as the sealed cask and natural convection air-cooled vault. In general, more heat per unit storage space can be dissipated using dynamic storage systems.

The water basin concept is selected as the reference short-term storage concept for SHLW at the FRP based on the availability of established technology developed from the 30-years' industrial experience with safe and successful storage of spent reactor fuel.

The sealed storage cask concept is selected for the longer-aged SHLW and longer-term contingency storage to be used in case a geologic repository is not available. This selection is based on concept studies and facility development in the United States and on similar concepts used in Canada for fuel storage and on the recommendation of a National Academy of Sciences (NAS) panel.[5] The sealed storage cask concept is considered advantageous over other methods because in this passively cooled system each SHLW package is individually well protected and significant package heat generation rates can be allowed. However, other storage concepts, such as subsurface storage (described for spent fuel in Section 5.7.5), could be used with reasonable extensions of existing technology.

For the facilities described here, it is assumed that the HLLW from a 2000-MTHM reprocessing plant is converted to SHLW immediately after separation, 1.5 years after discharge from a nuclear power plant, and packaged in 0.3 m dia x 3 m long (1 x 10 ft) canisters. The packaged SHLW is stored in a water basin associated with the FRP for 5 years to permit the heat generation rate to decline to a level that is acceptable at either a geologic repository or an extended storage facility. The SHLW packages are then shipped by rail to a geologic repository. If a repository is not available, the SHLW packages are shipped to a sealed-storage-cask interim storage site. Radioactivity content and heat generation rates at separation, 2 years after separation and 5 years after separation are shown in Table 5.4.2.

TABLE 5.4.1. Comparison of Solidified High-level Waste Storage Concepts

	Sealed Storage Cask Concepts			Air-Cooled Vault Concept	Water Basin Concept	Water Basin Concept With Overpacked Containers
	Concrete Shielded	Thick Wall	Thin Wall			
Cooling method	Air natural circulation	Air natural circulation	Air natural circulation	Air natural circulation	Water-forced circulation and cooling towers	Water-forced circulation and cooling towers
Confinement method	5-cm wall sealed carbon-steel cask welded closure	35-cm wall sealed carbon-steel cask welded closure	20-cm wall sealed carbon-steel cask welded closure	1.3 cm wall carbon steel overpack welded closure	Water-filled steel-lined concrete basin	1.3-cm wall, stainless steel overpack welded closure water-filled basin
Biological shielding	97-cm thick concrete sleeve	30-cm thick concrete sleeve	None (distance)	Concrete vaults	Water basin	Water basin
Storage concept	Vertical outdoor on 6-m centers	Vertical outdoor on 6-m centers	Horizontal outdoor 6-m apart	Vertical indoor	Vertical indoor	Vertical indoor
Maximum normal operating temperature, °C						
Canister (outer surface)	243[a]	232[a]	235[a]	327[b]	<53	251
Overpack (outer surface)	118[a]	77[a]	82[a]	204[b]	NA[c]	53
Concrete (inner surface)	68[a]	50[a]	NA	93[b]	NA	NA
Dose rates, mrem/hr	2 (concrete sleeve surface)	2 (concrete sleeve surface)	14,000 (cask surface)	<2 (top of deck)	<1 (water surface)	<1 (water surface)

a. 27°C ambient air temperature.
b. 43°C ambient air temperature.
c. NA = Not applicable.

TABLE 5.4.2. Radioactivity Content and Heat Generation Rate in Solidified High-level Waste(a)

Radionuclides	0 Years After Separation(b)	2 Years After Separation(b)	5 Years After Separation(b)
Fission Products, Ci/MTHM			
$^{90}Sr + {}^{90}Y$	1.2×10^{5}	1.2×10^{5}	1.1×10^{5}
$^{95}Zr + {}^{95}Nb$	1.1×10^{4}	4.6	3.9×10^{-5}
$^{106}Ru + {}^{106}Rh$	3.8×10^{5}	9.4×10^{4}	1.2×10^{4}
$^{134}Cs + {}^{137}Cs + {}^{137m}Ba$	3.0×10^{5}	2.3×10^{5}	1.8×10^{5}
$^{144}Ce + {}^{144}Pr$	4.8×10^{5}	8.2×10^{4}	5.6×10^{3}
All other FPs	1.0×10^{5}	5.6×10^{4}	2.5×10^{4}
Total FPs	1.4×10^{6}	5.8×10^{5}	3.3×10^{5}
Actinides Ci/MTHM			
^{239}Pu	1.8	1.8	1.8
^{241}Pu	8.7×10^{2}	8.0×10^{2}	6.9×10^{2}
Other Pu	3.1×10^{1}	8.0×10^{1}	8.3×10^{1}
$^{242}Cm + {}^{244}Cm$	1.7×10^{4}	7.1×10^{3}	5.9×10^{3}
All other actinides	1.0×10^{3}	9.9×10^{2}	9.2×10^{2}
Total actinides	1.9×10^{4}	8.9×10^{3}	7.6×10^{3}
Heat Generation Rate, W/MTHM	7.1×10^{3}	2.8×10^{3}	1.4×10^{3}

a. Based on waste characterization Table 3.3.29 and assuming U and Pu recycle.
b. 1.5 years elapse between reactor discharge and chemical separation.

5.4.1 Water Basin Storage for Solidified High-level Waste

The method and technology used to store packaged SHLW[3] are basically the same as those used to store spent fuel elements[4] with different package contents and configuration. Thus the process and facilities subsequently described are adaptations of existing fuel storage facilities.

5.4.1.1 Solidified High-level Waste Water Basin Storage Alternatives

The SHLW is packaged in stainless steel canisters (described in Section 4.1) and placed in a deionized water pool. The pool is reinforced concrete lined with stainless steel and may be covered or open to the storage building. The water, maintained below 49°C (120°F), is treated by filtration and ion exchange.

Stainless steel is selected for the canister because of its integrity, corrosion resistance in water, and economy. Less expensive canisters, such as carbon steel, would corrode in water, which would affect water chemistry, make package integrity questionable, make visibility in the pool difficult, and make water decontamination more difficult. Other canister materials are considered too expensive. Overpacking the canister with a stainless steel container to provide added canister protection and radionuclide containment is an alternative that would be expensive for the incremental benefits gained. Therefore, overpacking was not included in the reference case.

The pool is lined with stainless steel, which provides an economical yet very high integrity liner. It also provides water and radionuclide containment and aids in the control of the water chemistry. A concrete-lined pool would not provide a high integrity water containment structure, would become contaminated with radionuclides (making decommissioning difficult), and would contaminate the water with dissolved chemicals. A mild steel liner would corrode and contaminate the water, causing the same problems as the mild steel canister and make the liner integrity questionable. Other features of the facility, such as package configuration, pool configuration, and equipment used for water treatment, are variables selected on the basis of economy and engineering preferences.

5.4.1.2 Solidified High-level Waste Water Basin Storage Facility Design Basis

The following assumptions were made in the design of the reference facility:

- The SHLW Water Basin Storage Facility (WBSF) is part of an operating FRP and obtains utilities and services from the FRP, except for heat, ventilation and air conditioning.
- Radionuclide-contaminated liquid waste generated at the WBSF is piped to the FRP for treatment.
- The WBSF receives packaged SHLW on a cart via a water-filled transfer canal. The receiving rate is compatible with the FRP reprocessing rate of 2000 MTHM/yr.
- The SHLW is stored for 5 years (storage space for the SHLW from reprocessing 10,000 MTHM of spent fuel is needed).
- Shipping facilities are included as part of the storage facility design.

- The packages of SHLW received at the WBSF are described in Section 4.1.
- SHLW packages that fail in storage are returned to the FRP for overpacking.
- The facility design is based on a concept described in Reference 1.

The water basin storage facility is designed and constructed to have a useful operational life of at least 50 years.

The facility is designed to assure the health and safety of the public and the protection of the environment, to include the ability to remove heat and maintain container integrity and retrievability following extended periods of time and to withstand all credible natural forces.

5.4.1.3 Solidified High-level Waste Water Basin Storage Facility Operations

Figure 5.4.1 is a flow diagram that shows the operations of the SHLW water basin storage facility. The sealed and decontaminated canisters filled with SHLW are transferred from the FRP to the storage facility on a cart under water through a transfer canal. The water cover provides radiation shielding protection for operating personnel. When the cart arrives in front of the basin in which the waste is to be stored, the canister is removed from the cart by the storage area crane and placed in a storage rack contained within the basin. The cart is returned to the FRP for reuse. When 500 canisters are stacked in double-tiered racks in a basin, the water seal door is closed and the next basin is used.

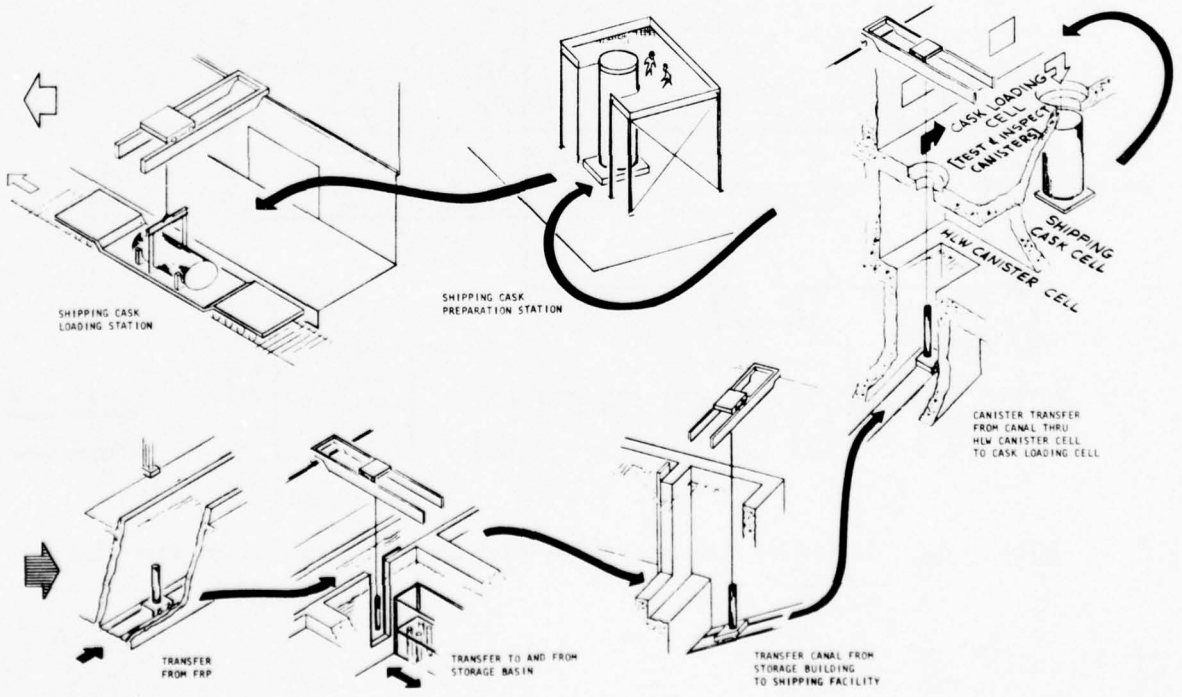


FIGURE 5.4.1. Solidified High-level Waste Water Basin Storage Facility Process Flow Diagram

Each basin is equipped with a pump and heat exchanger system to maintain basin water temperature below 49°C (120°F) and canister surface temperature below 53°C (128°F). Water purity is maintained at less than 10 ppm chloride by passing part of the circulated cooling water through a filtration and ion exchange system. The radiation dose rate at the surface of the water in the basins is estimated to be less than 1 mrem/hr. Ion exchangers and filters are regenerated in place.

After about a 5-year storage period, the canisters are individually removed from the racks and moved by cart through a water-filled transfer canal to beneath the cask loading cell. There the canister is lifted by crane into the cell and transferred to a shipping cask for transport to a repository. The shipping facility has the ability to receive, inspect, decontaminate, cool, load, and ship filled casks as well as the capability to handle and decontaminate the transport vehicle and to provide some limited cask lag storage capacity.

5.4.1.4 Solidified High-level Waste Water Basin Storage Facility Description

The SHLW storage facility is attached to the FRP adjacent to the HLLW solidification process area (see Figure 4.1.2). The facility is divided into two areas, the storage area and the shipping facility, as shown in Figure 5.4.2.

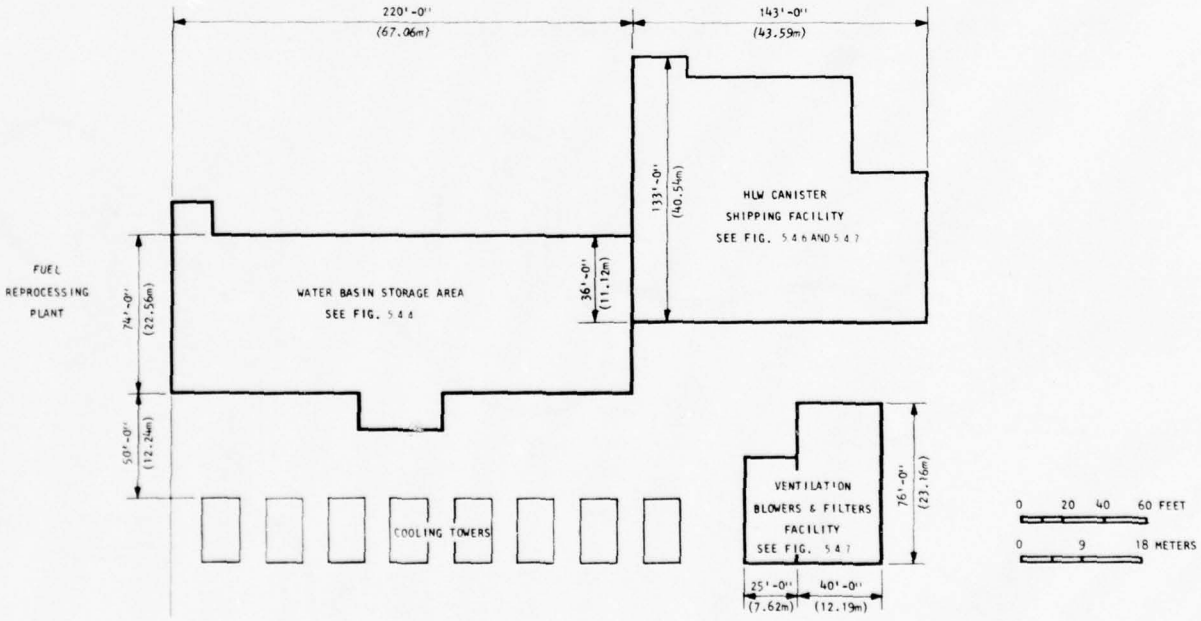


FIGURE 5.4.2. Solidified High-level Waste Water Basin Storage Facility Plot Plan

The WBSF contains eight basins which are below-grade, water-filled pools that receive and store solidified HLW. Basin water is circulated within the storage building through heat exchangers, filters and an ion exchanger for removal of heat and radioactive contamination. Heat, removed by the constant circulation of the basin water in direct contact with the canisters, is transferred to the secondary cooling loop and rejected to the atmosphere from standard, open, forced-draft cooling towers located outside the storage building. A diagram of the system is shown in Figure 5.4.3.

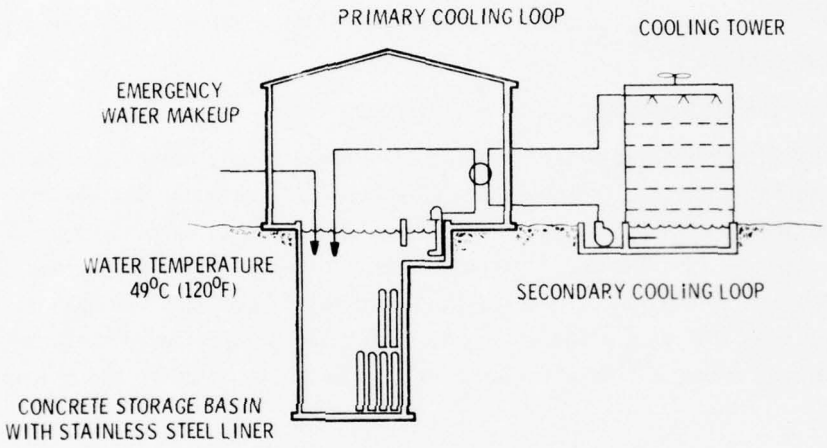


FIGURE 5.4.3. Solidified High-level Water Basin Storage Facility Heat Removal System

The canister shipping facility has the capability of receiving the HLW canisters taken from the basins and moving them into remote cells for inspection and testing. Canisters of proven integrity are placed into shipping casks and loaded onto rail cars or trucks for offsite transportation. The water basin and shipping facilities share FRP utilities, services, and support facilities such as personnel areas, laboratories, health physics, warehousing, shops and maintenance.

The WBSF has the capacity to receive and store more than 5 years' production of SHLW from the FRP. The reference FRP produces approximately 3300 canisters of borosilicate glass over a 5-year period. Basin storage capacity in seven pools is 3500 HLW canisters 0.3 m (1 ft) in dia by 3 m (10 ft) long. The WBSF also has a spare pool with a storage capacity for 500 additional canisters.

The WBSF has a design heat removal capacity of 9 MW per basin. If the FRP reprocesses spent fuel 1.5 years after reactor discharge, and if the HLW is solidified immediately after reprocessing, each canister of vitrified HLW can have an initial heat generation rate as high as 22 kW that is reduced to approximately 12 kW after one year and to less than 5 kW after 5 years storage. The shipping facility is designed for a maximum of 10 kW per canister, but canisters are normally not shipped until the heat generation rate is less than 5 kW per canister.

General Facility Arrangement. The WBSF is adjacent to the HLW calcination/vitrification cell, which is an integral part of the primary FRP process buildng. Figures 5.4.4 through 5.4.8 show the general facility arrangement.

Reference 1 outlines the design bases for the facilities, systems, and equipment and has been used as the basis for most of the design features. Modifications to the design are as follows:

A water canal transfer system is used to move the canisters from the FRP waste solidification cell to the water basins.

- The receiving facility described in Reference 1 is modified to become the canister shipping facility.
- Emergency electrical power is supplied from the FRP.

Water basin storage facilities consist of a row of eight basins covered by an insulated, dust-tight building which also houses the 20-ton bridge crane and the basin water cooling and treating equipment. The canisters of solidified HLW are transferred out of the solidification area of the FRP and into the water basin through a water canal which extends the length of the WBSF building across the end of each basin. Each reinforced concrete basin is 11 m (36 ft) long, 5.8 m (19 ft) wide and 11.6 m (38 ft) deep, containing double-tiered storage racks for 500 canisters. The basins are filled with demineralized water which cools and shields the waste.

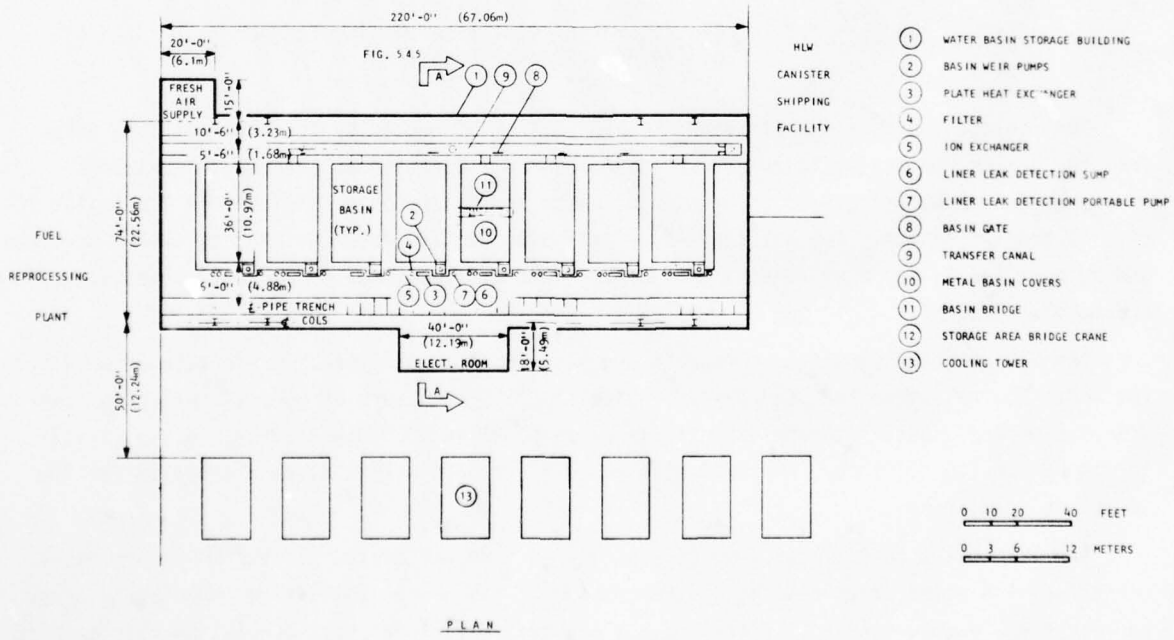


FIGURE 5.4.4. Solidified High-level Waste Water Basin Storage Area, General Arrangement

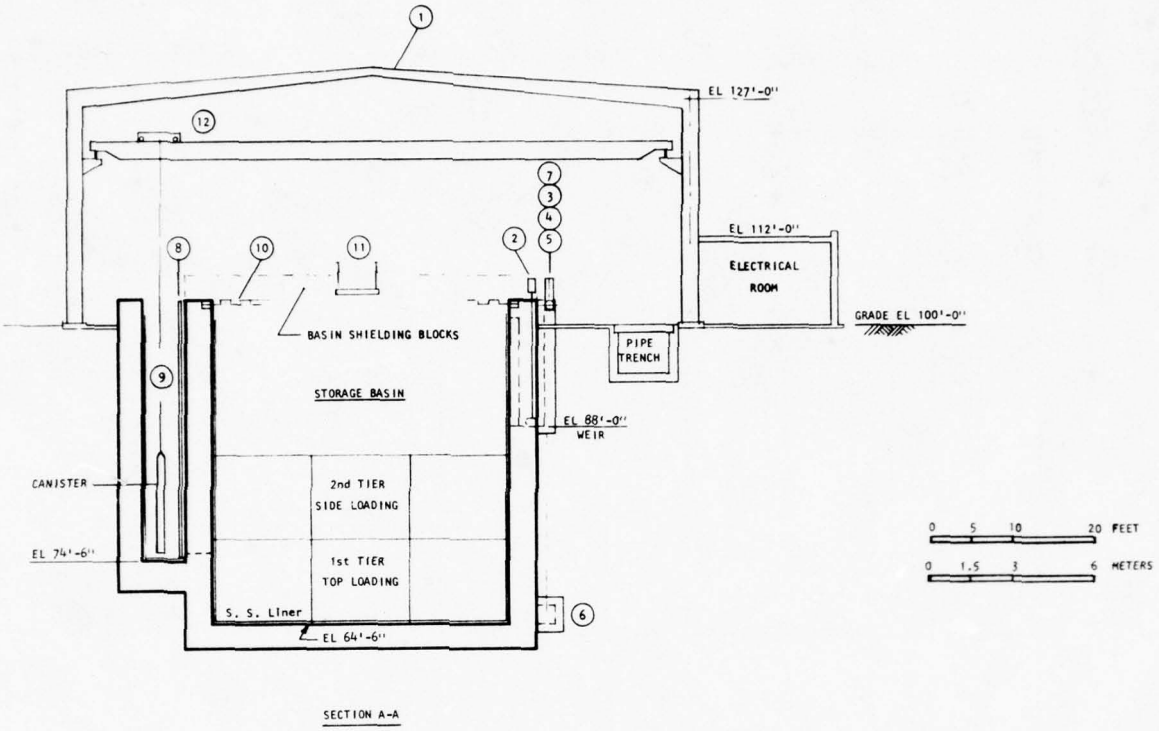


FIGURE 5.4.5. *Solidified High-level Waste Water Basin Storage Area, Section A-A* (See Figure 5.4.4 for key to circled numbers.)

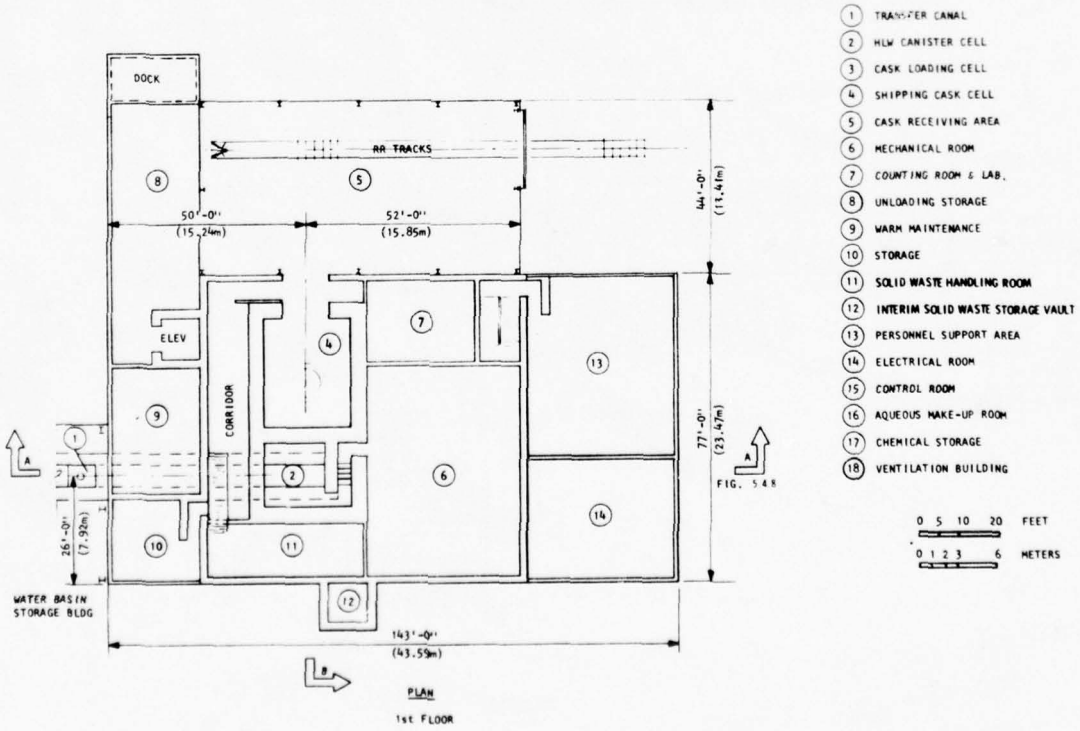


FIGURE 5.4.6. Solidified High-level Waste Water Basin Storage Facility Shipping Area, 1st Floor Plan

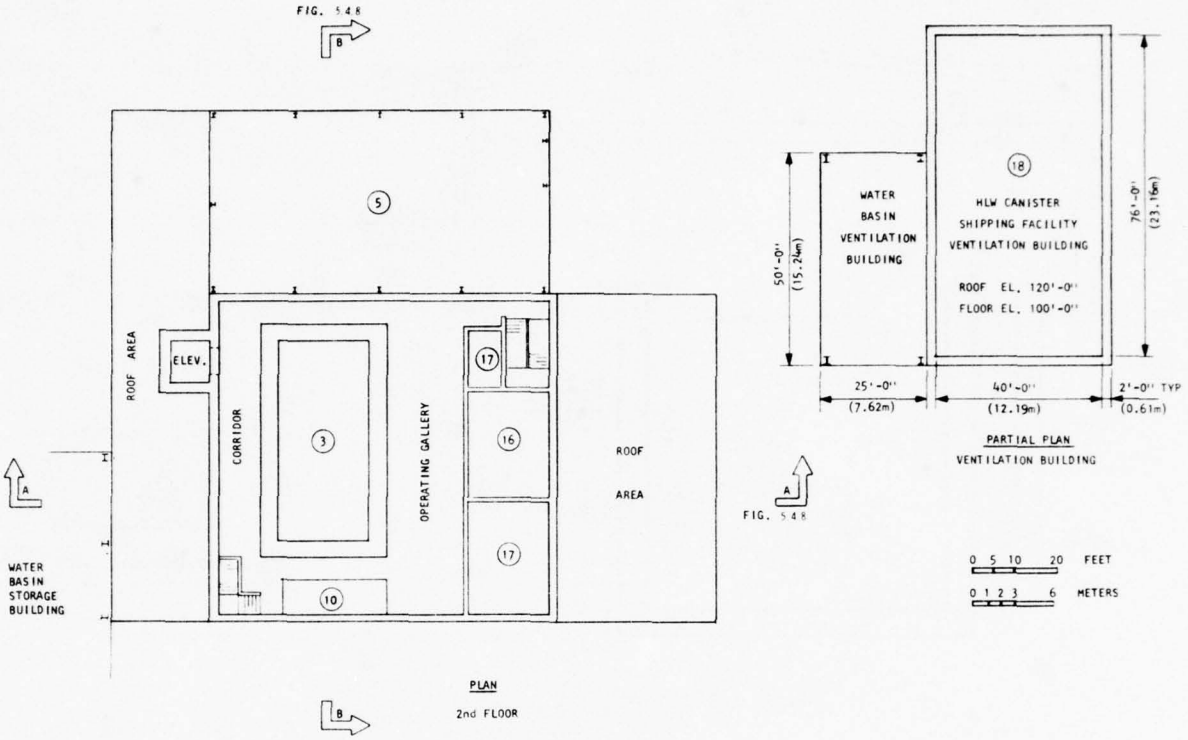


FIGURE 5.4.7. Solidified High-level Waste Water Basin Storage Facility Shipping Area, 2nd Floor Plan (See Figure 5.4.6 for key to circled numbers.)

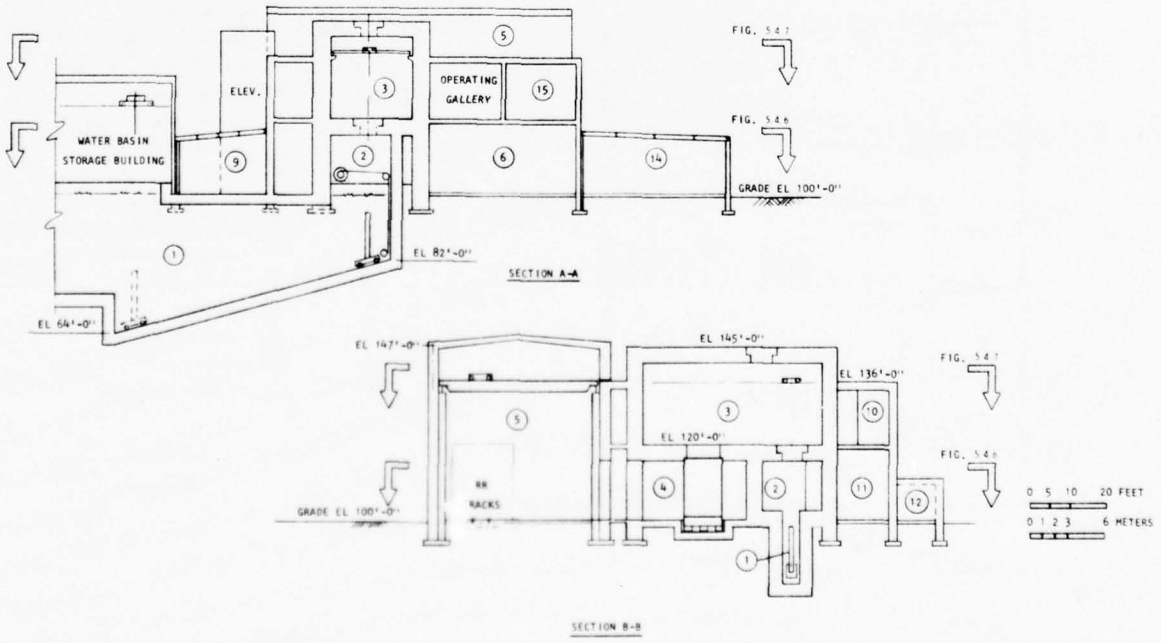


FIGURE 5.4.8. Solidified High-level Waste Water Basin Storage Facility Shipping Area, Sections A-A and B-B (See Figure 5.4.6 for key to circled numbers.)

The SHLW canister shipping facility is capable of shipping canisters removed from the water basins, to an offsite repository. The shipping facility includes a cask receiving area, mechanical and electrical rooms, a personnel areas, and various other service and support facilities.

Structures. The water basins and the canister handling crane and its support structure are designed as Category I structures. The canal and basins are lined with stainless steel, and all underwater components are stainless steel, including the storage racks. The basin enclosure building, the electrical room, the ventilation fan house, and the cooling towers are of standard commercial construction.

All parts of the canister shipping facility that enclose unprotected canisters are Category I, including the cask loading cell, the canister transfer cell, the shipping cask cell, the operating gallery, the control room, the solid waste handling room, the exhaust filter fan building, the shipping cask crane plus its support structure. All equipment required to maintain essential services are also Category I.

Systems and Equipment . The systems and equipment used in this facility are similar to those described in Reference 1. Each basin water system is circulated through a stainless steel plate-type cooler for heat exchange to a secondary cooling water circuit. Each basin has an outside cooling tower to cool the secondary cooling water. Connections are provided in the basin water systems for installing a portable ion exchanger and filter to remove high-level radioactive contamination in case canisters are breached.

The emergency cooling water system is Category I design, to guarantee the supply of basin makeup water if the basin cooling water circulation is lost as a result of damage from a tornado, earthquake, or other credible forces.

Minimal facilities are provided for decontamination of shipping casks and transport vehicles. Radionuclide contamination should not be a major problem.

Shielding and Remote Handling Equipment. All areas of normal occupancy for operating personnel are shielded with 1.5 m (5 ft) of concrete, about 4 m (13 ft) of water, or canister casks to maintain normal exposure to $\leq$1 mrem/hr. Areas not normally occupied may have dose rates of up to 10 mrem/hr.

5.4.1.5 Solidified High-level Waste Water Basin Storage Facility Operating and Maintenance Requirements

The reference facility is designed to operate 24 hours a day, 7 days a week, the year around. Handling operations, such as placement of canisters within the storage pool, are usually performed only on normal day shift, assuming there is sufficient lag storage to hold SHLW packages in the solidification area. The waste shipment activities, usually performed on the week days during all shifts, may vary depending on the desired shipment schedule and method of operating the FRP. Basin monitoring activities are continuous. Other activities include sampling and maintenance operations.

All SHLW handling, storage, and shipping operations are performed remotely. In the storage area, SHLW operations are performed under water, which acts as a radiation shield. With about 4 m (13 ft) of water always between the SHLW and the water surface, the normal dose rate to operating personnel is $\leq$1 mrem/hr. Canister handling operations use remotely operated carts, canister racks, or crane. For canister shipping operations the canisters are again handled with a crane. During shipping operations, operating personnel are shielded from radiation by the "hot" cell walls or the shipping cask. Casks and SHLW operations for shipment are somewhat similar to those for spent fuel described in Section 5.7.1.

Maintenance of facilities located in the water pool is done semiremotely under water. If a piece of equipment located in the pool fails or is removed for repair, it is loaded into a cask under water; the loaded cask is removed to an appropriate area for unloading, or, if the contamination level is low enough, the equipment may just be loaded into a box on the facility deck. Maintenance operations in the cask loading cell may be remote, semiremote, or contact depending on the ability of plant operations to decontaminate it and on the nature of the item to be serviced. Other maintenance operations are normally contact maintenance since, except for low-level nuisance contamination, there are no loose radioactive contaminants in the facility. Shipping casks are maintained relatively contamination free. The facility is constructed to deal with radionuclide contamination, such as contaminated SHLW container surfaces, shipping cask interiors, and failed containers. Should a SHLW container fail during storage or handling, it is returned to the solidification facility for inspection and repackaging. If the water in any pool becomes significantly contaminated as a result of container failure, a set of concrete cover blocks is placed over the pool to reduce exposure to operating personnel. The pool water is isolated and circulated through a portable ion exchange cleanup system until sampling shows that the radiation is reduced to an acceptable level.

Staffing. Estimated staffing requirements for the facility are shown in Table 5.4.3.

Supplies and Utilities. Table 5.4.4 shows supply requirements for the facility. Table 5.4.5 lists the utilities required to operate the water basin storage facility.

Hazardous Materials. Except for the SHLW, the only hazardous materials in the SHLW water basin storage facility are the decontaminating agents, nitric acid, sodium hydroxide, and organics in the amounts shown in Table 5.4.4. Standard industrial precautions are used in handling these materials.

5.4.1.6 Solidified High-level Waste Water Basin Storage Facility Secondary Radioactive Wastes

Secondary radioactive wastes associated with the reference facility are shown in Table 5.4.6 Most of the secondary waste is generated during receiving and shipping operations.

5.4.1.7 Solidified High-level Waste Water Basin Storage Facility Emissions

Facility emissions are characterized in Table 5.4.7. The controlling release of radioactivity is assumed to be vaporization of excess water resulting from concentration of secondary wet wastes (Table 5.4.6). The values listed in Table 5.4.7 are based on a release factor of 10^{-6} in two sequential evaporation steps.

TABLE 5.4.3. Water Basin Storage Facility Staffing Requirements

Job Description	Personnel Required, man-yr/yr
Operators	21
Maintenance	8
Radiation monitors	3

TABLE 5.4.4. Water Basin Storage Facility Supply Requirements

Material	Use	Annual Requirement, m^3
Sodium hydroxide (5%)	Ion exchange bed regeneration	150
Nitric acid (5%)	Ion exchange bed regeneration	100
Detergent	Decontamination	2
Detergent	Cleaning	0.2

TABLE 5.4.5. Water Basin Storage Facility Utility Requirements

Utility	Use Rate	Annual Requirement
Electricity	5×10^3 kW	4.4×10^7 kWh
Water consumed	1.1×10^6 kg/day	4.1×10^8 kg
Oil (fuel)	1 m^3/day	380 m^3

TABLE 5.4.6. Solidified High-level Waste Water Basin Storage Secondary Waste

Description	Volume, m^3/year	Radioactivity Factors[a]	
Combustible and compactable waste	800	All	2×10^{-9}
Failed equipment	40	All	2×10^{-9}
Concentrated wet waste	20	Cs	2×10^{-7}
		All others	2×10^{-8}

a. Fraction of receipts and shipments activity in secondary wastes. For receipts and shipments use columns 1 and 3 of Table 5.4.2 and 2000 MTHM/yr-equivalent receipts and shipments rates.

TABLE 5.4.7. Solidified High-Level Waste Water Basin Storage Emissions

Emission	Description	Annual Quantity	Radioactivity Release Factors to Atmosphere[a]
Gaseous	Facility and process air and vaporized excess water	2.5×10^9 m^3	Cs = 2×10^{-13} All others = 2×10^{-14}
	Minor accident Integrated annual Release		None identified
Cooling tower tower	evaporated T = 38°C	3.5×10^8 kg	
	drift T = 38°C	1.7×10^6 kg	
	blowdown T = 27°C	6.1×10^7 kg	
Other	Heat	2.4×10^5 MW-hr (8.1×10^{11} BTU)	

a. Fraction of receipts and shipments activity released. For receipts and shipments use column 1 and 3 of Table 5.4.2 and 2000 MTHM/yr-equivalent receipts and shipments. Release is uniform over each year.

5.4.1.8 Solidified High-level Waste Water Basin Storage Facility Decommissioning Considerations

At the end of the reference facility's operating life, the storage area and shipping facility and the associated equipment are expected to be contaminated with about 1 to 10 Ci of mixed fission products with a 3-year equivalent time out of reactor. Plans for decontaminating and decommissioning the water basin storage facility must provide for appropriate decontamination equipment and systems and for monitoring and recording equipment needed to assess contamination levels. Ease of retirement and removal is an important consideration in selecting all materials and equipment for the facility. Any facility structure surfaces that are highly susceptible to hard-to-remove radionuclide contamination are covered with a removable surface.

5.4.1.9 Solidified High-Level Waste Water Basin Storage Facility Postulated Accidents

Safe storage of SHLW is the key design and operational goal of the storage facility. The facility is provided with highly reliable normal and emergency cooling, atmospheric protection, and containment systems. Staff at this facility is technically skilled in the operation of the

safety and confinement systems and is trained to handle emergencies. Although earthquakes or other disasters that exceed design basis provisions are extremely unlikely, the staff is trained to take whatever action necessary to maintain cooling water flow or to transfer the SHLW to a spare pool. Postulated minor, moderate, and severe accident scenarios for the reference water basin storage facility are given in Tables 5.4.8, 5.4.9, and 5.4.10.

Following a cooling water interruption, it is estimated that self-heating would bring the pool water to the boiling point in roughly one shift, with the pool boiling dry in about 2 days. Within this time the incident can be controlled by assuring proper off-gas treatment, resuming cooling water flow, and/or adding makeup water when needed. Independent cooling and makeup water supplies are present. The staff is trained to take immediate action to assure a cooling water supply. Credible cooling water interruptions are included in the minor category since no radioactivity release would occur during loss of normal electrical power or loss of normal secondary coolant supply.

An explosion resulting from accumulation of hydrogen produced by radiolytic decomposition of pool water is not considered a credible accident. The water basin facility is designed to prevent hydrogen accumulation by ventilation air flow over the pool. In addition, there is no ignition source in the pool area.

5.4.1.10 Solidified High-Level Waste Water Basin Storage Facility Costs

Estimates have been made, in mid-1976 dollars, of capital, operating and levelized unit costs. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for the water basin storage and shipping facility is shown in Tables 5.4.11 and 5.4.12. Since the canisters of solidified HLW may require up to 5-years residence in the water storage basins, it is possible to schedule the construction of the shipping facility significantly later than the storage area. For this reason, cost estimates and other information for the two parts of the facility are presented separately.

The estimates cover all capital costs specifically resulting from the inclusion of the WBSF as an integral part of the FRP. All basins are completely equipped with a full complement of storage racks, primary and secondary water circulating, cooling and treating systems. The costs also include the effect of incremental additions to FRP utilities supplied to the WBSF, including emergency electrical power and emergency cooling water as well as the normal electrical power, water and air supplies. No allocation of general FRP costs is made to the WBSF for such services as laboratories, warehouses and shops.

The total capital cost for both components is $84 million ±30. and includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation, with the exception of working capital. The SHLW shipping costs are not estimated here but are included in the SHLW transportation costs (Section 6.3.1).

TABLE 5.4.8. *Postulated Minor Accidents for the Solidified High-Level Waste Water Basin Storage Facil ty*

Accident No. and Description	Sequence of Events	Safety System	Release
5.4.1 – Loss of normal electrical power, expected frequency of 0.2/yr.	1. Power to substation supplying facility interrupted. 2. Equipment motion stops. 3. Emergency power supplied to facility. 4. Operations resumed.	1. Automatic breaker activated by power loss. 2. Emergency diesel generator.	None
5.4.2 – Loss of normal cooling water supply, expected frequency-0.2/yr.	1. Cooling water supply stops due to power outage. 2. Emergency power supplied to cooling water pumps.	1. Emergency diesel generator.	None
5.4.3 – Reduction of normal cooling water supply, expected frequency -0.25/yr.	1. Pump or heat exchanger fails. 2. Temperature begins to slowly rise in pool. 3. Emergency cooling provided. 4. Pool temperature reduced to normal.	1. Pools have temperature instrumentation and alarms. 2. Back-up pumps are installed.	None
5.4.4 – Ventilation system failure, expected frequency -0.25/yr.	1. Failure of exhaust or supply fan motor. 2. Back-up system automatically starts up.	1. Redundant ventilation exhaust and supply fans.	None
5.4.5 – Leak in water treatment system, expected frequency 0.25/yr.	1. Gasket fails, pool water leaks to floor. 2. Leakage enters sump and triggers an alarm. 3. Leakage returned to pool and leak repaired. 4. Spill area decontaminated.	1. Leak collection system and alarms.	None
5.4.6 – Failure of secondary cooling loop.	1. Pump, fan or piping failure. 2. Redundant cooling supply starts up. 3. Equipment repaired or replaced before serious increse in water temperature. 4. Normal cooling resumed.	1. Spare cooling tower or once-through cooling capability available. 2. Piping designed for quick equipment replacement.	None

TABLE 5.4.9. Postulated Moderate Accidents for the High-Level Solid Waste Water Basin Storage Facility

Accident No. and Description	Sequence of Events	Safety System	Release
5.4.7 – Canister failure in storage basin.	1. Canister breached by impact or corrosion. 2. Radiation level in basin increases. 3. Leaking canister detected and removed for overpacking. 4. Concrete cover blocks deployed to control worker exposures. 5. Portable ion exchange equipment installed to decontaminate basin water.	1. Lifting heavy objects over pool minimized. 2. Corrosion resistant stainless steel canisters used, demineralized water used in basin. 3. Redundant radiation sensors and alarms monitor pool water. 4. Failed canister detection equipment. 5. Set of pool cover blocks maintained at the facility. 6. Connections for ion exchange equipment provided.	None, (Possible increased worker exposure.)
5.4.8 – Failure of basin liner.	1. Basin liner fails due to corrosion or impact. 2. Leakage drains to sump. High water level in sump alarms. 3. Leakage pumped to treatment equipment and makeup water added to maintain water level. 4. SHLW transferred to spare pool. 5. Basin Emptied and repaired. 6. Basin returned to service.	1. Basin water chemistry controlled. Basin liner is stainless steel. 2. Redundant leak detection systems. 3. Concrete basin contains leakage. 4. Make up capacity sized to mitigate leakage. 5. Spare basin always available.	None
5.4.9 – Dropping shipping cask into cask well.	1. Equipment failure or operator error drops 40 ton shipping cask into cask well. 2. Cask inspected and is expected to be undamaged. 3. Impact absorber removed and replaced.	1. Impact absorber minimizes cask damage.	None
5.4.10 – Dropping canister into storage basin.	1. Equipment failure or operator error drops canister into storage basin. 2. Canister unlikely to fail. Removed to FRP for inspection and repair (if needed).	1. Bottom of canister prevented from being more than 6.7 m (22 ft) above basin floor. 2. See systems 4 through 6 in accident 5.4.7. (if failure occurs).	None, (Possible increased worker exposure.)
5.4.11 – Failure of primary cooling loop.	1. Pipe, pump or heat exchanger failure. 2. Failure detected. 3. Failed equipment replaced before serious increase in water temperature	1. Equipment instrumented for leak detection and temperature rise. 2. Secondary cooling loop at higher pressure to minimize leakage. 3. Piping designed for quick equipment replacement.	None

TABLE 5.4.10. Severe Accidents for the High-level Waste Water Basin Storage Facility

Accident No. and Description	Sequence of Events	Safety Systems	Release
5.4.12 – Concrete cover block falls into storage pool.	1. Lifting bail failure or operator error drops cover block into basin. 2. Storage racks distorted. Possibility of several failed canisters. 3. Recovery would consist of steps 3 through 5 of accident 5.4.6 followed by damaged rack replacement.	1. Blocks not used unless surface shielding required. 2. Special operating procedures are followed when blocks are used. 3. See numbers 4 through 6 of accident 5.4.6.	None. (Possible increased worker exposure.)
5.4.13 – Contamination of secondary cooling water.	1. Gross failure of heat exchanger and inability to maintain a higher pressure in the secondary cooling water system. 2. Activity in secondary system detected and alarms sound. 3. Failed secondary system shut down. 4. Redundant cooling supply starts up at a high enough pressure to minimize out-leakage from the primary system. 5. Failed equipment replaced.	1. Equipment instrumented for pressure differentials and leak detection. 2. Spare cooling tower or once-through cooling available. 3. Piping designed for quick equipment replacement. 4. Spare pool always available.	It is conservatively estimated that if 10% of the primary coolant loop (contaminated to 2×10^{-4} Ci/m^3) leaks into the secondary coolant that 1.8×10^{-5} Ci of mixed fission products and actinides would be released at ground level in 10 minutes.
5.4.14 – Fire in storage basin building.	1. Fire starts in basin building. 2. Fire detected. 3. Fire extinguished. 4. Damaged equipment replaced or repaired.	1. Limited amount of combustible material in facility. 2. Fire detectors and alarms. 3. Redundant water sprinklers and portable extinguishers.	None
5.4.15 – Design basis tornado; expected frequency 1×10^{-5}/yr.	1. Tornado strikes facility. 2. During the single pass, the roof fails, exposing the pool water. 3. Some basin water is entrained by the tornado and transported offsite.	1. Building roof designed to "blow away" in a tornado to prevent structural damage. 2. Radioactive radwaste system are tornado-proof so are undamaged.	Conservatively assumed to entrain 16.5 MT of water which releases instantaneously at ground level 3.3×10^{-3} Ci of mixed fission products.

Operating Costs. The annual operating costs for the storage and shipping facilities are shown in Table 5.4.13. Estimates of operating labor and utilities are based on requirements given in Tables 5.4.3 and 5.4.5. There are no process materials for the storage facility since the stainless steel canister costs were included in the treatment facility (Section 4.1). Annual maintenance material costs are estimated at 2% of the initial equipment investment. Overhead and miscellaneous costs are calculated as explained in Section 3.8. Miscellaneous costs include water treatment chemicals for the basin and as well as all other unidentified operating costs. The costs of taxes, insurance, and interest, however, are included in the capital segment of the levelized unit cost.

Levelized Unit Costs. The levelized unit cost estimate, including levelized capital and operating costs for both storage and shipping facilities, is shown in Table 5.4.14. The unit cost calculation assumes private ownership of the facilities and a 15-yr economic life.

TABLE 5.4.11. Capital Cost for Water Basin Facility Storage Area

Cost Element	Storage Area				
	Man-hours, 1000s		Costs, 1000s Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		110	6,700	1,300	8,000
Buildings and structures		630	3,500	7,600	11,100
Bulk materials		240	2,700	2,900	5,600
Site improvements		10	100	100	200
Subtotal of Direct site construction costs		990	13,000	11,900	24,900
Indirect site construction costs	260	200	4,300	5,800	10,100
Total Field Cost	260	1,190	17,300	17,700	35,000
Architectural-Engineering services					7,000
Subtotal					42,000
Owner's cost					13,000
Total cost					55,000
Estimated accuracy range					±30%

TABLE 5.4.12. Capital Cost for Water Basin Facility Shipping Area

Cost Element	Shipping Area				
	Man-hours, 1000s		Costs, 1000s Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		10	800	100	900
Buildings and structures		370	2,200	4,400	6,600
Bulk materials		210	1,900	2,600	4,500
Site improvements		10	100	100	200
Subtotal of Direct site construction costs		600	5,000	7,200	12,200
Indirect site construction costs	160	120	2,700	3,400	6,100
Total Field Cost	160	720	7,700	10,600	18,300
Architectural-Engineering services					3,700
Subtotal					22,000
Owner's cost					7,000
Total cost					29,000
Estimated accuracy range					±30%

TABLE 5.4.13. Solidified High-Level Waste Water Basin Storage and Shipping Operating Cost Estimate

Cost Element	Annual Costs, $1000s Storage	Shipping
Direct labor	300	170
Process materials	0	0
Utilities	700	230
Maintenance materials	160	20
Overhead	420	200
Miscellaneous	170	90
Total	1750 +50% -25%	710 +50% -25%

TABLE 5.4.14. Solidified High-Level Waste Water Basin Storage Facility Levelized Unit Cost Estimate

Cost Element	Unit Cost, $/kg HM Storage	Shipping
Levelized capital charge	6.90	3.60
Levelized operating charge	.90	.40
Levelized total unit cost	7.80 ±40%	4.00 ±40%

5.4.1.11 Solidified High-Level Waste Water Basin Storage Facility Construction Requirements

Many of the factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information which follows provides a basis for evaluating the impact of construction activities.

Project Schedules and Construction Manpower. The schedule for engineering, procurement and construction of the WBSF is an integral factor in the overall schedule for the FRP, which is described in Section 3.2.3. The field labor man-hours estimated for the construction of the storage basins and the canister shipping area are tabulated below:

	Storage	Shipping
Manual field labor	1190	720
Nonmanual field labor	260	160
Total field labor	1450	880

Construction of the shipping facility may be deferred for up to 5 years after construction of the FRP. An estimated engineering, procurement and construction (EPC) schedule for independent construction of the shipping facility is shown separately in Figure 5.4.9. The graph showing labor force and distribution for this schedule is shown in Figure 5.4.10.

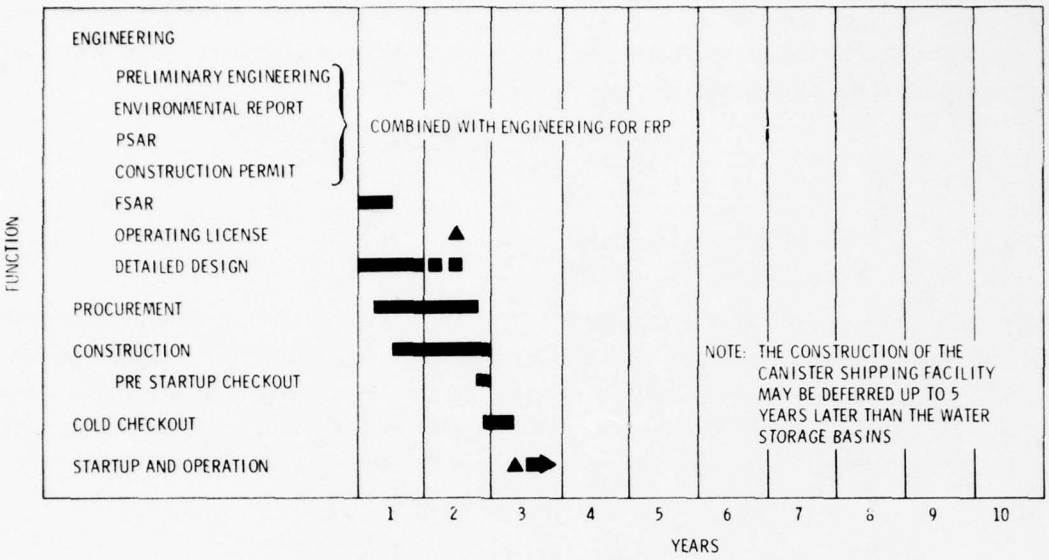


FIGURE 5.4.9. Engineering, Procurement, and Construction Schedule for the Solidified High-level Waste Water Basin Storage Facility Shipping Area

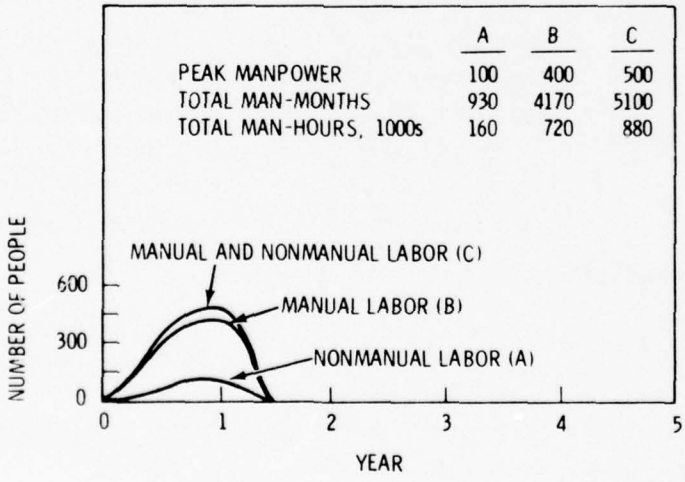


FIGURE 5.4.10. Construction Labor Force Schedule for the Solidified High-level Waste Water Basin Storage Facility Shipping Area

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site. Offsite costs are those for all services provided, equipment fabricated or assembled, and materials purchased elsewhere. The distribution of total costs in these categories is shown below:

	Costs, 1000s of Mid-1976 Dollars	
	Storage Area	Shipping Facility
Onsite	19,000	11,000
Offsite	36,000	18,000
Total	55,000	29,000

Site Requirements. The WBSF is adjacent to the calcination/vitrification process area at the FRP and requires additional access roads, parking areas and a rail spur inside the FRP plant area. The same construction facilities used for the FRP are used for the WBSF. Land commitments are included with those for the FRP. Within the FRP site, adjacent to the main process building, the following approximate land areas are required for the WBSF:

Water basin storage	0.6 ha	(1.5 Acres)
Canister shipping facility	0.6 ha	(1.5 Acres)

Water. Water used during the construction period is expected to be as follows:

	Storage Area	Shipping Facility
Water consumed	1500 m^3 (4 x 10^6 gal)	11000 m^3 (3 x 10^6 gal)

Construction Materials. Construction materials committed to the reference facility are:

	Storage Area	Shipping Facility
Concrete	5700 m^3 (7500 yd^3)	3820 m^3 (5000 yd^3)
Steel	2000 MT (2200 Tons)	820 MT (900 Tons)
Copper	36 MT (40 Tons)	45 MT (50 Tons)
Zinc	4.5 MT (5 Tons)	3 MT (3 Tons)
Lumber	472 m^3 (200 MBFM)	236 m^3 (100 MBFM)

Energy. Energy resources used during construction are:

	Storage Area	Shipping Facility
Propane	151 m^3 (40,000 gal)	76 m^3 (20,000 gal)
Diesel fuel	1510 m^3 (400,000 gal)	757 m^3 (200,000 gal)
Gasoline	1140 m^3 (300,000 gal)	379 m^3 (100,000 gal)
Peak demand (kW)	300	300
Total consumption (kWh)	700,000	400,000

Transportation Requirements. The railroad track into the shipping facility is a branch from the main spur of the FRP. No other separately identifiable transportation requirements for the WSBF have been identified beyond those for the FRP.

5.4.1.12 Effects of Fuel Cycle Options

The reference process for water basin storage of SHLW assumes reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to SHLW interim storage.

No Recycle. Eliminating the fuel reprocessing operation does away with the generation of high-level liquid wastes. Accordingly, no SHLW storage facilities are required.

Uranium Recycle Only, with Plutonium to Storage. This alternative is expected to generate about the same amount of SHLW as in the uranium and plutonium recycle case. No significant change in the facility design is anticipated.

Uranium Recycle Only, with Plutonium to High-level Waste. This alternative would also generate about the same quantity of SHLW as in the uranium and plutonium recycle case. However, additional considerations would have to be made for the storage of the SHLW regarding criticality safety.

A criticality safety analysis has been conducted for the interim storage of canisters of solidified high-level waste in a water basin, assuming the plutonium is discarded to high-level waste. The analysis indicates that some form of canister spacing control may be required to assure criticality safety.

Two alternative forms of solidified waste are considered: fluidized-bed calcine SHLW in 20 cm (8 in.) dia canisters and vitrified SHLW in 30 cm (12 in.) dia canisters. Although $k_{\infty} = 1.313$ for the calcine, the values of k_{eff} for full canisters 3 m (10 ft) long are only 0.207 and 0.145 for full concrete and water reflection, respectively. Thus, the handling of single calcine canisters and the storage of large numbers of such canisters in water on 46 cm (18 in.) centers will be critically safe. Although some restrictions on the stacking of large numbers of bare calcine canisters is required, they would not be severe since 50 canisters stacked together would be subcritical.

Criticality safety control for the vitrified waste canisters depends on whether or not the plutonium oxide tends to concentrate owing to precipitation and settling during the glass-making operation. If the plutonium is homogeneously distributed, k_{∞} is much less than 1, and no additional criticality control is required. However, if the distribution of plutonium is not homogeneous, some geometry and spacing controls may be required. This criticality question cannot be fully resolved until experimental information on the solubility of plutonium in waste glass becomes available (see Section 4.1.1).

5.4.2 Sealed Storage Cask for Storage of Solidified High-level Waste

The sealed storage cask (SSC) concept for extended interim storage of solidified high-level waste (SHLW) has previously been studied extensively.[1,2] The concept used here places a SHLW canister in a high integrity metal storage cask, which is contained in a reinforced concrete radiation shield. Air circulates by natural convection between the shield and storage cask (sealed cask) to remove heat being generated from the SHLW. Although this concept is not presently being utilized, it is based on existing well-developed technology and is being full-scale tested[3] using electrically heated dummy SHLW packages at DOE's Hanford Project. The concept is somewhat similar to a concept being used in Canada to store reactor fuel.[4]

5.4.2.1 Sealed Storage Cask Alternatives

Three significant alternatives have been calculated for the sealed storage cask concept.[1,2,5] These are the shielded, thick wall, and unshielded concepts; they are compared in Table 5.4.1. The shielded cask concept was selected for the reference facility here because of its relative economy and potentially reduced radiation exposure to the environment and operating personnel and because of its selection by the NAS panel.[5]

Within the basic concept, some engineering optimization can be performed to improve the safety, integrity, and reliability of the concept. For instance, use of different shielding materials, such as high-density concrete or a steel-water composite could be investigated. Also, various configurations could be reviewed to minimize the shielding material. Various cask construction materials could also be considered, such as stainless steel and nickel alloys. These are corrosion-resistant, stronger at elevated temperatures, and require less material for the same strength; however, they are also more expensive.

5.4.2.2 Sealed Storage Cask Facility Design Basis

The following assumptions were made for the design of the reference facility:

- The storage facility is an independent facility. All supporting facilities and services are provided as part of the storage facility, including SHLW waste receiving, overpacking, shipping, handling of secondary waste, operating personnel facilities, security, and utilities.
- The canister handling and storage-unit assembly capacity is designed for modular expansion as needed.
- The facility has an initial capacity to store 2000 canisters of SHLW and can be expanded in 2000 canister modules to an ultimate capacity of 20,000 canisters.
- Waste containers are received over a 10-year period after which the waste packages are retrieved and shipped to a geologic repository where it becomes available. The SHLW canisters are not removed from their storage casks prior to shipment to a disposal repository.
- The facility receives canisters of SHLW which are 30 cm (1 ft) in dia x 3 m (10 ft) in length, as described in Section 4.1.1. Each canister contains the HLW from 3.04 MTHM. The waste heat generation is the equivalent of reference fuel 6.5 years out-of-reactor so that each canister generates about 4.4 kW of heat.

- Only one SHLW storage cask is placed in each concrete shield.
- The storage facility is designed for 100-year operation.
- The facility design is based on a facility conceptual design developed by Atlantic Richfield Hanford Company for SHLW handling and storage.[2]

5.4.2.3 Operation of Sealed Storage Cask Facility

The flow diagram in Figure 5.4.11 illustrates the operations at the sealed storage cask facility. A shipping cask loaded with canisters containing SHLW is delivered to the shipping cask receiving area by rail car or truck. The cask and rail car, or truck, are externally surveyed for contamination and are washed down to remove dirt accumulated during transit. Facilities are provided for minor decontamination if required.

Shipping casks received in a horizontal position are upended and placed on the shipping cask transporter by the receiving crane. The casks are moved to the cask preparation station for cooling (if required), venting, and monitoring of the shipping cask internal atmosphere for contamination.

The shipping cask shield plug retainer is removed, the cask-to-port seal installed, and the cask moved into the shipping cask cell beneath the receiving cell. The shipping cask on the transporter is raised by a hydraulic lift table to seal the cask to the underside of the shipping cask access port.

Storage casks and radiation shields, arriving by rail car or truck, are stored outside adjacent to the receiving and assembly facilities. These casks and shields are brought on a transporter into the storage unit assembly area as required for cask weld preparation, cask shield plug installation, and assembly of the empty storage unit.

The empty storage unit is moved to the storage cask cell beneath the receiving cell and raised by a hydraulic lift table to couple with a seal attached to the underside of the storage cask access port. Prior to transfer of a canister from the shipping cask to the storage cask, the receiving cell crane removes, and stores within the receiving cell the access port covers from both the shipping cask cell and the storage cask cell and the shield plugs from both casks.

The waste canister is moved from the shipping cask into the receiving cell by the receiving cell crane; it is inspected visually through a shielding window and checked for contamination using a manipulator. If contamination is detected, the canister is placed in a spray chamber and cleaned with liquid sprays to help maintain clean welding surfaces and a clean cask weld test facility (CWTF). The clean canister is lowered into the storage cask, an air seal is installed, and the storage cask shield plug is replaced. The air seal is installed as an additional safety measure to prevent the air, possibly contaminated, in the storage cask from escaping. Prior to welding, the weight of the shield plug is expected to hold the air seal in place. Should this weight prove to be insufficient, a mechanical hold-down device is used to help maintain the vapor seal.

The lift table is lowered and the storage unit is moved to the CWTF. This canister transfer procedure is continued until all canisters are removed from the shipping cask.

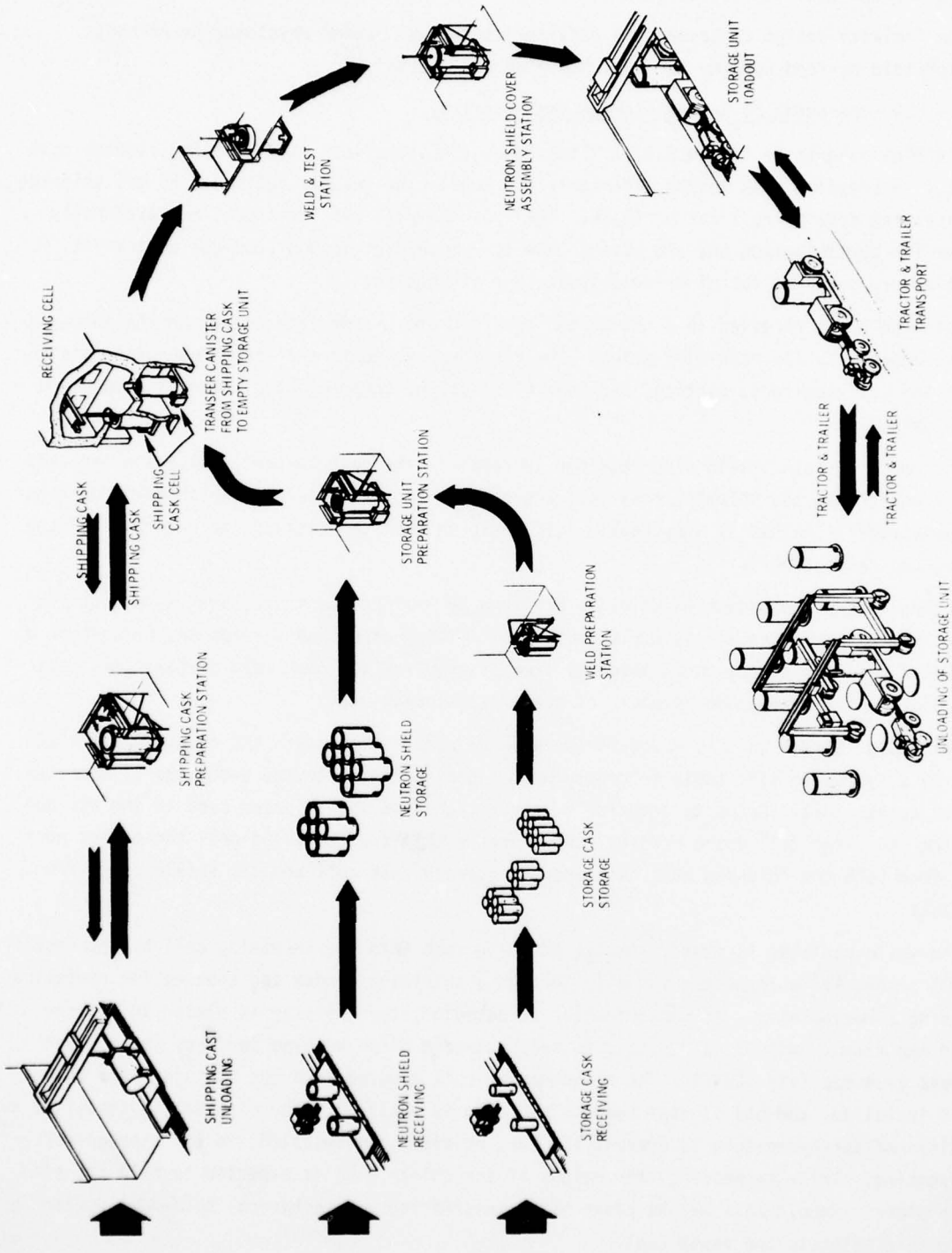


FIGURE 5.4.11. Operations Flow Diagram for the Sealed Storage Cask Facility

At the CWTF, 7.5 cm (3 in.)-thick plates are welded into the top of the cask cavity above the shield plug. The welds are checked by nondestructive testing, and weld repairs are made if required. After the satisfactory completion of welding and testing, the storage cask is moved to the storage unit assembly area for installation of the radiation shield cover, the final step in storage unit assembly.

After the radiation shield cover is installed, the storage unit is loaded on the trailer of the tractor-trailer transporter by the receiving crane and hauled to the sealed cask storage area. The storage area gantry crane lifts the storage unit from the trailer and places it on a prepared concrete storage pad. The tractor-trailer transporter is returned to the storage unit assembly area to receive the next storage unit. A conceptual picture of the storage area and the gantry crane is shown in Figure 5.4.12.

Routine surveillance and maintenance activities in the storage area include periodic inspection of the storage area, removal of debris from the air inlets to the storage units, manning of the control room, maintenance of a security force, routine plant maintenance, and records keeping.

Other peripheral process operations at the facility include waste and process building ventilation air treatment. Liquid waste generated from shipping cask, canister, or facility operations is concentrated and immobilized with cement. Solid waste is also packaged for storage. Facility process building air is monitored and filtered prior to atmospheric release. In the highly unlikely event that a failed canister is received or that a cask and canister in storage loses its integrity, the canister is retrieved and/or overpacked prior to placement in a cask (or in a new storage container).

5.4.2.4 Sealed Storage Cask Facility Description

The sealed storage cask facility (SSCF) consists of a large hot cell building for receiving the SHLW canisters and assembling them into the storage units as well as a storage area adjacent to the receiving facility. A typical storage unit is shown on Figure 5.4.13. The SSCF is capable of receiving canisters of solidified HLW from the FRP, encapsulating them in secondary heavy-walled steel casks, placing each cask in an individual concrete radiation shield, and placing these storage units in a grid pattern on the top of the ground within a fenced, controlled area. The doubly-contained high-level waste is air-cooled by natural convection inside the concrete shield. It is well protected from both natural and man-made forces and is shielded to protect facility workers and the general public from radiation. The plot arrangement for the SSCF is shown in Figure 5.4.14.

General Facility Description

The SSCF is capable of storing 20,000 canisters. The initial storage area is constructed for storage of 2000 units and has provisions for incremental expansion up to the total 20,000 units or more. The SSCF receiving and assembly facilities are sized to handle canisters up to 60 cm (24 in) dia and up to 4.6 m (15 ft) long. However, the storage area is based on receiving and storing 20,000 canisters of waste, 30 cm (12 in) dia x 3 m (10 ft) long.

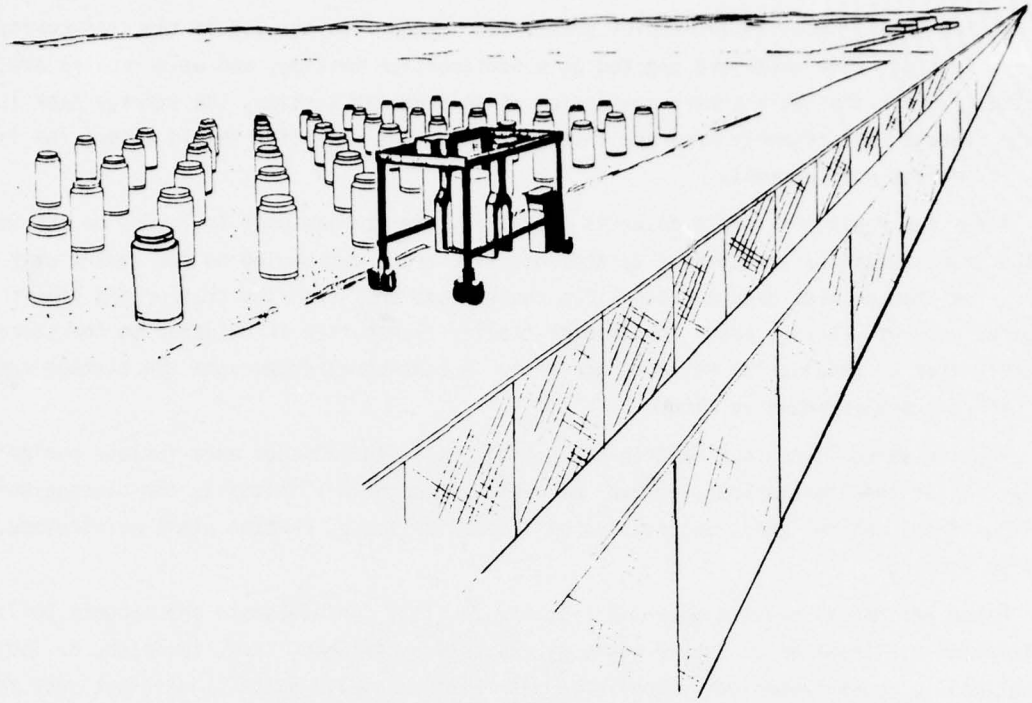


FIGURE 5.4.12. Sealed Storage Cask Area

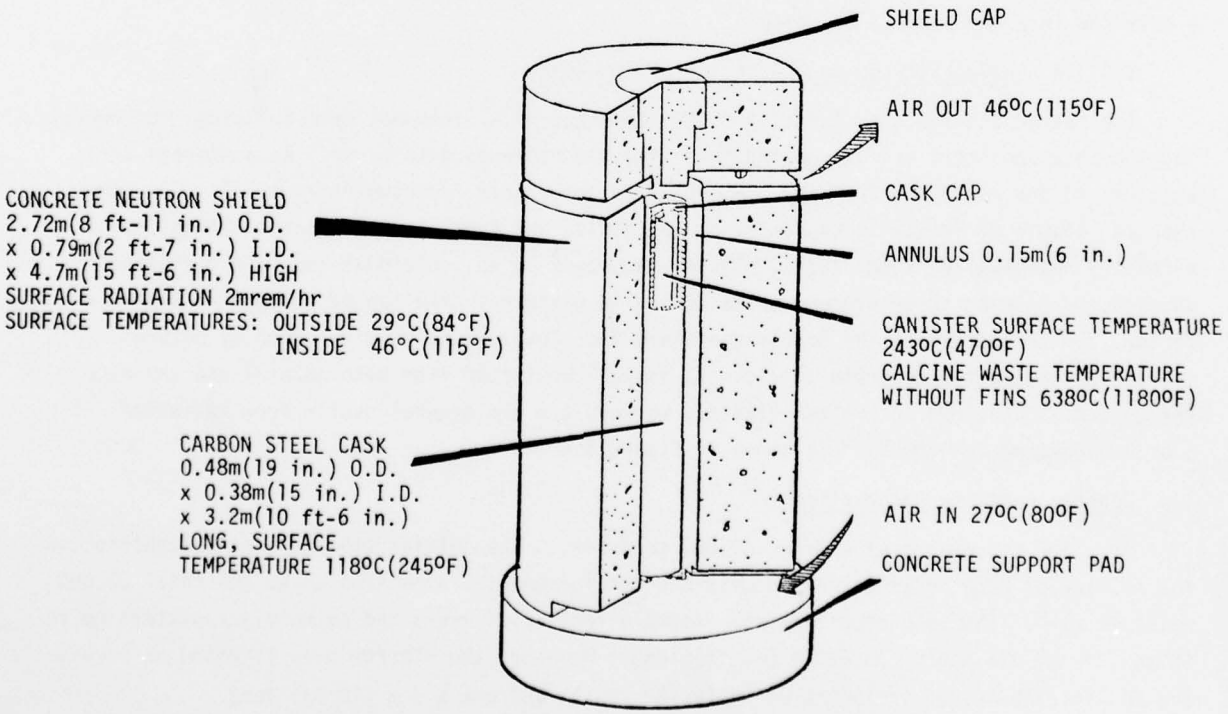


FIGURE 5.4.13. Sealed Storage Cask Facility Storage Unit

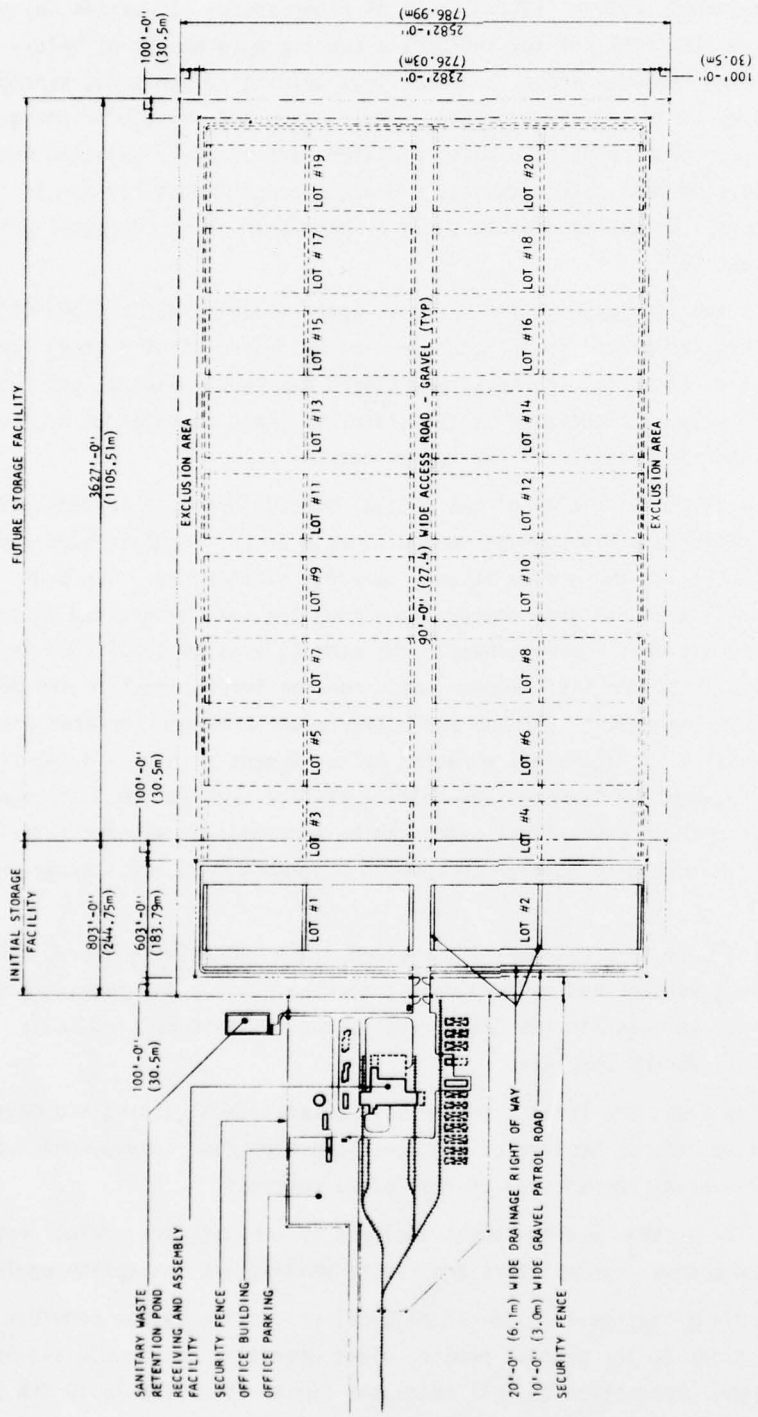


FIGURE 5.4.14. Sealed Storage Cask Facility Plot Plan

Receiving and Assembly Building. A prototype of this building and its associated facilities are described in detail in Reference 2. The building is steel-framed and reinforced concrete structure with approximately 2800 m^2 (30,000 ft^2) of floor space. It varies in height from about 3.7 to 17.4 m (12 to 57 ft) and includes a considerable amount of below-grade construction. The building includes areas for receiving; welding and testing; storage unit assembly; mechanical and electrical supply; heating, ventilation and air conditioning; hot and cold maintenance; and personnel support. Waste canisters are remotely unloaded from the shipping casks in the receiving cell, are examined, and are decontaminated further if necessary, in the spray chambers. Defective canisters can be placed in steel overpacks prior to transfer to the weld and test cell.

The weld and test cell is two stories high and encloses approximately 140 m^2 (1500 ft). In this cell, the SHLW canisters are placed into right circular cylinders of mild steel (casks) having a wall thickness of 5.1 cm (2 in.). The casks are closed by remote welding, and the welds are examined nondestructively. If the weld is defective, the weld is repaired or the cask is cut open and the canister is transferred into a new cask.

Storage Area. Figure 5.4.15. shows a plan of the initial storage area. A loaded storage unit is placed on a tractor-trailer and transported to the storage area. A mobile yard gantry picks the storage unit off the trailer and places it on a concrete storage pad. The pads are arranged on a 5.2 x 7.3 m (17 x 24 ft) grid pattern such that the yard gantry can maneuver between them and have access to any unit for retrieval. The storage area is subdivided into lots accommodating 1000 storage units per lot. Access roads for the tractor-trailer are 90 feet (27.4 m) wide to allow ample turning areas. Ditches and culverts are arranged for area drainage. A patrol road surrounds the initial storage area, bordered by two fences with a 15 m (46 ft) well-lighted exclusion strip between the fences. The initial storage area for 2000 storage units is laid out for periodic modular expansions, which can be accomplished without interfering with simultaneous operation. The ultimate storage area would accommodate 20,000 storage units and could be further expanded.

Structures. The receiving cell is a Category I structure. The operating gallery, control room, electrical room, standby generator and battery rooms, service gallery and receiving pit are also Category I, as required to maintain the Category I status of the receiving cell. The Category I areas are made of reinforced concrete.

In general, other building areas are steel framed with insulated metal siding and have built-up roofing over rigid insulation. Because of the functional building arrangement, some non-Category I areas are within areas constructed of reinforced concrete.

Systems and Equipment. The systems and equipment employed in the SSCF are typical remote area handling devices, such as cranes, manipulators and remote welding and inspection equipment.

Shielding and Remote Handling Equipment. The radiological protection system provides protection from all radiation hazards to the general public, plant operating personnel, and vegetation and wildlife in the area. Protection to well below the limits specified in 10 CFR 20[6] is provided and external and internal direct radiation exposure to the public and operating personnel is limited to as low as is reasonably achievable.

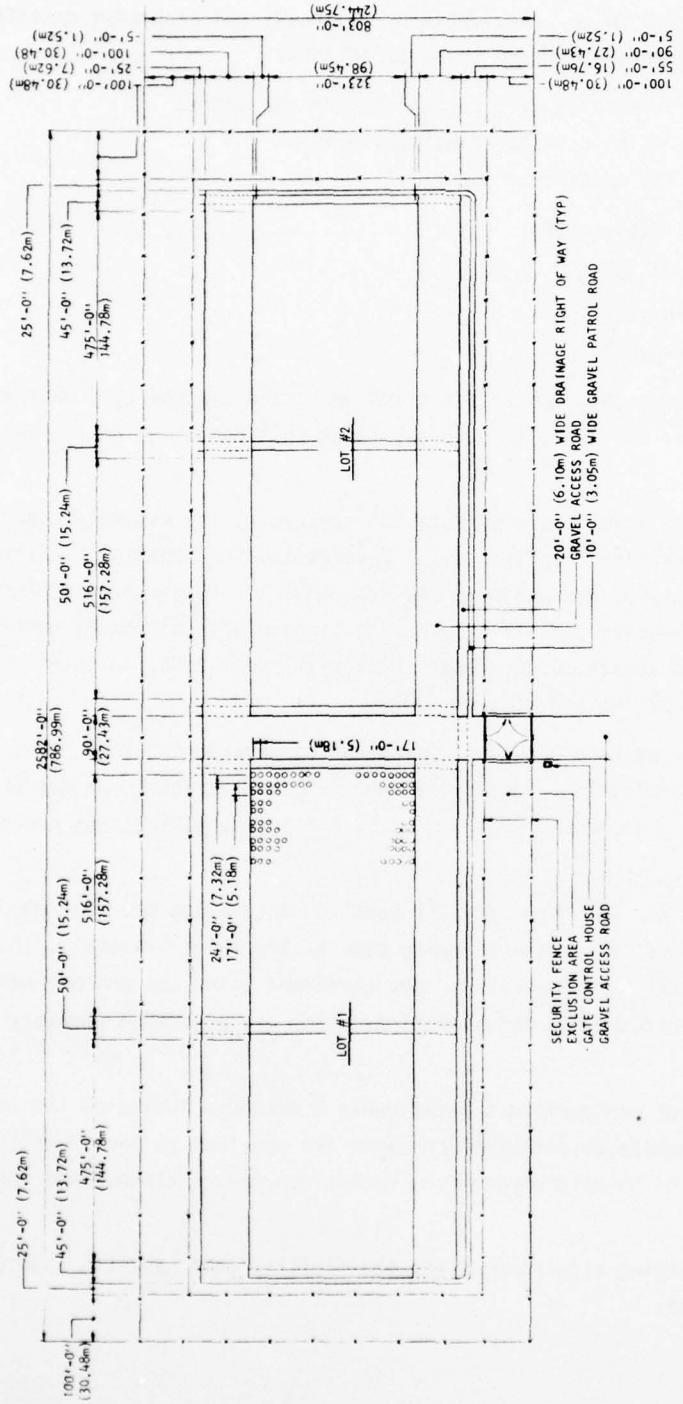


FIGURE 5.4.15. SSCF Storage Area

5.4.2.5 Sealed Storage Cask Facility Operating and Maintenance Requirements

The reference facility is designed to operate 24 hr/day, 7 days/week, the year around. The bulk of the waste is expected to be transported by railroad, and each cask contains 9 SHLW canisters. Facility capacities are estimated to be as follows:

Receiving - 87 casks/year per shift (783 canisters/year per shift)
Assembly of storage units - 180 canisters/year per shift
Storage unit placement - 780 units/year per shift.

Capacity requirements are estimated to be:

1990	700 canisters/year
1995	1200 canisters/year
2000	1800 canisters/year.

The initial capacity requirements can be satisfied operating one shift, 5 days/week for receiving and storage placement and two shifts, 5 days/week in the storage unit assembly operations.

Assuming the assembly facilities could operate 300 days/year, the assembly capacity is 800 units (canisters)/year operating 3 shifts/day, 7 days/week. The handling facilities would require a modular expansion in 1991 and again in the year 1999 if storage requirements are continued beyond that date. However, both receiving and storage unit placement operations could be handled with only two shifts, 5 days/week through the year 2000. A total of 14,800 canisters would be in storage by the end of year 2000.

Other operations, such as waste processing, maintenance, warehousing activities, transportation vehicle handling, and administration services normally are performed on day shift. Activities related to storage area monitoring, security, and supply of services are performed around the clock.

Operations and Maintenance. All SHLW canister handling activities are performed remotely. When the canisters are contained, as in the shipping cask or the shield assembly, they can be handled by contact methods. All other operations are performed using contact methods except for secondary liquid waste concentration and packaging, which are performed remotely or semiremotely.

All maintenance activities are performed using contact methods, including the receiving cell and weld test cell. Adequate decontamination means are provided to permit cell entries. The storage area is designed to be maintenance-free except for ground cleanup and general road and fence servicing.

Staffing. Estimated staffing requirements for the facility when handling 1800 canisters/year are shown in Table 5.4.15.

TABLE 5.4.15. Sealed Storage Cask Facility Staffing Requirements

Job Description	Personnel Required, man-yr/yr
Operators	33
Maintenance	23
Radiation monitors	12

Supplies and Utilities. Table 5.4.16 shows supplies used in storage facility operations. Table 5.4.17 lists the utilities required to operate the storage facility.

TABLE 5.4.16. Sealed Storage Cask Facility Supply Requirements

Supply	Use	Annual Requirement
Carbon steel storage casks	SHLW storage	657/2000 MTHM
Concrete radiation shields (includes bases)	SHLW storage	657/2000 MTHM
Detergent	Decontamination	Small
Concrete	Waste packaging	Small

TABLE 5.4.17. Sealed Storage Cask Facility Utility Requirements

Utility	Use Rate	Annual Requirements
Electricity	3.6×10^3 kW	3.2×10^7 kWh
Oil (fuel)	1.8 m^3/day	660 m^3

Hazardous Materials. Standard commercial chemicals, used for decontamination work, could include inorganic acids, caustics and solvents. Other than the high-level waste itself, no other hazardous materials are handled.

5.4.2.6 Sealed Storage Cask Facility Secondary Radioactive Wastes

Secondary radioactive wastes associated with the reference facility operation are shown in Table 5.4.18.

5.4.2.7 Sealed Storage Cask Facility Emissions

Facility emissions are characterized in Table 5.4.19. The controlling release of radioactivity is assumed to occur during concentration of secondary wet wastes (Table 5.4.18). The value listed here assumes that a release factor of 10^{-6} is provided by two sequential evaporation processes.

TABLE 5.4.18. Sealed Storage Cask Facility Secondary Wastes

Description	Volume, m^3/year	Radioactivity Factors[a]	
Combustible and compactable waste	140	All	1×10^{-10}
Failed equipment	30	All	1×10^{-10}
Concentrated wet waste	30	All	1×10^{-10}

a. Fraction of annual receipts activity in secondary wastes. For receipts activity use column 3 of Table 5.4.2 and 2000 MTHM/yr - equivalent receipts.

TABLE 5.4.19. Sealed Storage Cask Facility Emissions

Emission	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere[a]	
Gaseous	Facility ventilation air and vaporized excess water	5×10^9 m^3	All	1×10^{-16}
	Minor accident integrated annual release		None identified	
Other	Heat	3.2×10^5 MW-hr[b] (1.1×10^{12} BTU)		

a. Fraction of year 2000 receipts activity released. For receipts activity use column 3 of Table 5.4.2 and 5500 MTHM/yr - equivalent receipts. Release is uniform over each year.
b. Based on 14,800 canisters accumulated in year 2000.

5.4.2.8 Sealed Storage Cask Facility Decommissioning Considerations

At the end of the reference facility's operating life, process cells, facilities and associated equipment are expected to be contaminated with 1 to 10 Ci of mixed fission products with a 10-year equivalent time out of reactor. Plans for decontaminating and decommissioning must provide for appropriate decontamination equipment and systems and for monitoring and recording equipment needed to assess contamination levels. Ease of retirement and removal is an important consideration in selecting all materials and equipment for the facility. Any facility structure surfaces that are highly susceptible to hard-to-remove radionuclide contamination are covered with a removable surface.

5.4.2.9 Sealed Storage Cask Facility Postulated Accidents

Safe storage of SHLW is the key design and operational goal of the sealed storage cask facility. The storage units have a highly reliable and passive cooling system. Containment is provided by multiple, high integrity barriers. Staff at this facility are technically skilled in the operation of the safety and confinement systems and are trained to handle all types of emergencies.

Postulated minor and moderate accident scenarios for the reference process and storage facility are given in Tables 5.4.20 and 5.4.21. No accidents that could be classified as severe accidents could be realistically postulated for this facility.

TABLE 5.4.20. Sealed Storage Cask Facility
Minor Accidents

Accident No. and Description	Sequence of Events	Safety System	Release
5.4.16 – Receipt of externally contaminated shipping cask.	1. Cask leakage in transport or inadequate cask cleaning at FRP prior to shipment.	1. Cask designed for transportation environment.	Negligible
	2. Radiation survey on receipt detects contamination.	2. Cask surveyed for activity before shipment.	
	3. Cask decontaminated before unloading.	3. Wash down equipment provided.	
	4. Decontamination solutions are concentrated and solidified before disposal.		
5.4.17 – Receipt of contaminated or failed canisters.	1. Canister failure in transport or inadequate cleaning before shipment.	1. Shielded facility.	Negligible
	2. Contamination detected.	2. Smear and air tests performed in receiving cell.	
	3. Canister decontaminated.	3. Wash down facilities provided.	
	4. Failed canisters are repackaged.	4. Overpack facilities provided.	
5.4.18 – Impaired waste cooling.	1. Storage unit cooling airflow restricted by dust, airborne vegetation or debris.	1. Surveillance and cleanout as needed will prevent or correct flow obstruction.	None
	2. Waste temperature rises until equilibrium is reached.	2. The storage cask will not exceed 650°F even with a complete flow blockage.	

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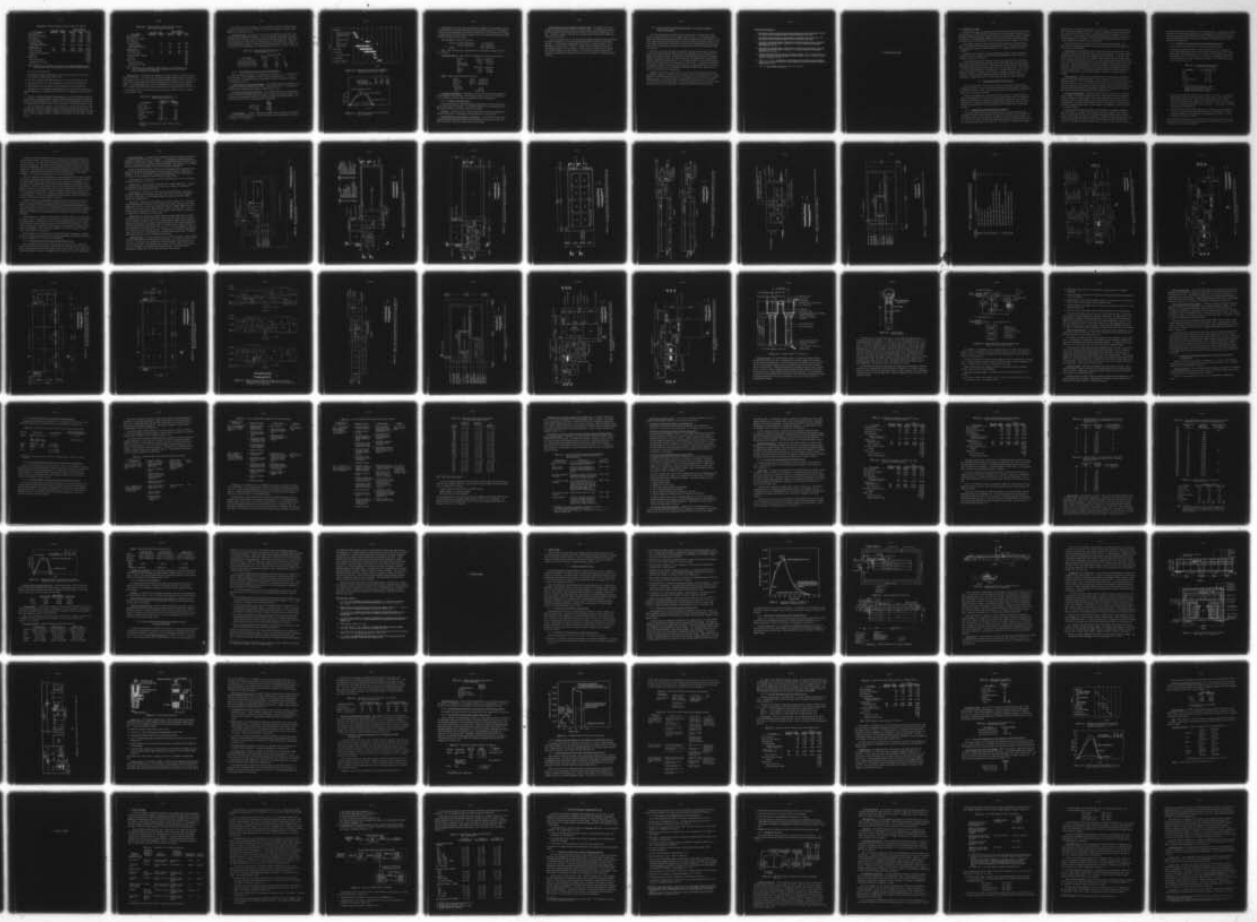


TABLE 5.4.22. Sealed Storage Cask Facility Capital Cost Estimate

Cost Element	Man-hours, 1000s		Costs, $1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		40	8,500	400	8,900
Buildings and structures		560	6,600	7,000	13,600
Bulk materials		680	12,700	8,000	20,700
Site improvements		240	2,300	3,000	5,300
Subtotal of direct site construction costs		1,520	30,100	18,400	48,500
Indirect site construction costs	400	400	6,600	9,000	15,600
Total field cost	400	1,920	36,700	27,400	64,100
Architect-engineer services					11,500
Subtotal					75,600
Owner's cost					15,400
Total facility cost					91,000
Estimate accuracy range					±25%

Note: Components for 500 storage units, consisting of concrete radiation shields and carbon steel casks, are estimated at an additional $6,500,000 total cost.

The initial phase consists of:

- all receiving, assembly, administration, security, and support facilities shown in solid outline on the plot plan, Figure 5.4.14
- an initial storage area for 2000 storage units (Lots #1 and #2 on the plot plan)
- concrete pads, within the initial storage area, for the first 200 storage units
- rough grading only of the remainder of the storage area (Lots #3 through #20).

The cost of an initial inventory of fabricated parts for the first 500 storage units is reported separately as a footnote to Table 5.4.22 and is not included in the total facility cost.

The site is intended for modular future expansion up to a total of 20,000 storage units. After startup, the required additional concrete foundation pads and components for storage units are considered operating costs. Table 5.4.23 gives the estimated cost to add one 2000 unit storage area, and the unit cost for field construction of the foundation pads is noted.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation with the exception of working capital. A reliable supply of electrical power is assumed to be available to the site without additional cost. A supply of suitable raw water is expected to be obtained from local wells or surface sources.

TABLE 5.4.23. Incremental Cost to Add One 2000 Unit Storage Area to Sealed Storage Cask Facility

Cost Element	Man-hours, 1000s		Costs, $1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment					
Buildings and structures					
Bulk materials					
Site improvements		13	300	160	460
Subtotal of direct site construction costs		13	300	160	460
Indirect site construction costs	4	3	60	80	140
Total field cost	4	16	360	240	600
Architect-engineer services					100
Subtotal					700
Owner's cost					200
Total facility cost					900
Estimate accuracy range					±20%

Note: The unit cost for storage cask foundation pads is not included above. The unit total field cost for these pads in quantities of one to two hundred units is estimated to be $4,000 each.

Operating Costs. The operating cost components for sealed storage cask storage of SHLW are shown in Table 5.4.24. Direct labor costs are based on manpower estimates given in Table 5.4.15. Process material and utility costs are derived from requirements shown in Tables 5.4.16 and 5.4.17. The radiation shields, carbon steel casks and concrete pads are estimated to cost $17,000 per assembly. Annual maintenance material costs are estimated at 3% of initial major equipment costs. Overhead and miscellaneous costs are estimated using the method described in Section 3.8.

An additional $5 million for expansion of the storage unit assembly capacity is provided in 1991 and again in 1999.

TABLE 5.4.24. Operating Cost Estimate[a] for the Sealed Storage Cask Facility

Cost Element	Annual Costs, $1000s		
	Loading		Unloading
Direct labor	1,150		1,160
Process materials	30,700		
Utilities	630		630
Maintenance materials	360		360
Overhead	1,370		1,370
Miscellaneous	*280*		*280*
Total	34,400	±25%	3,800

a. Based on a year 2000 receipt rate of 1800 HLW canisters per year.

The estimates for the miscellaneous items are intended to include all unidentified operating costs. The cost of taxes, insurance and interest are included in the capital charge segment of the levelized unit cost.

Levelized Unit Costs. Table 5.4.25 lists the total levelized unit cost as well as the levelized capital and operating components. The cost calculations assume Federal ownership. The table shows the effect on costs of storing SHLW accumulations through 1990, 1995 and 2000. These accumulations are 2200, 7700, and 14,800 canisters of SHLW, respectively. SHLW waste storage requirements are based on a 400 GWe nuclear generating capacity in the year 2000. The unit capital costs drop appreciably as a larger fraction of the facility capacity is utilized.

TABLE 5.4.25. Levelized Unit Cost Estimate for the Sealed Storage Cask Facility

Cost Element	Unit Cost, $/kg HM		
	Accumulation to 1990	to 1995	to 2000
Levelized capital charge	17.50	6.50	4.20
Levelized operating charge	10.50	7.30	6.80
Levelized total unit cost	28.00 ±20%	13.80 ±20%	11.00 ±20%

5.4.2.11 Sealed Storage Cask Facility Construction Requirements

Many of the factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information which follows provides a basis for evaluating the impact of construction activities.

Project Schedules and Construction Manpower. The estimated schedule for engineering, procurement and construction schedule for the SSCF is shown on Figure 5.4.16. The construction labor force size, composition and schedule is shown on Figure 5.4.17.

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials and services provided at the site of the SSCF, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is shown below:

	Costs, $1000s
Onsite costs	29,000
Offsite costs	62,000
Total	91,000

Site Requirements. The SSCF is located on government land, with access to the facility by road or railroad transportation. The facility should not be located adjacent to a population center or in a flood plain.

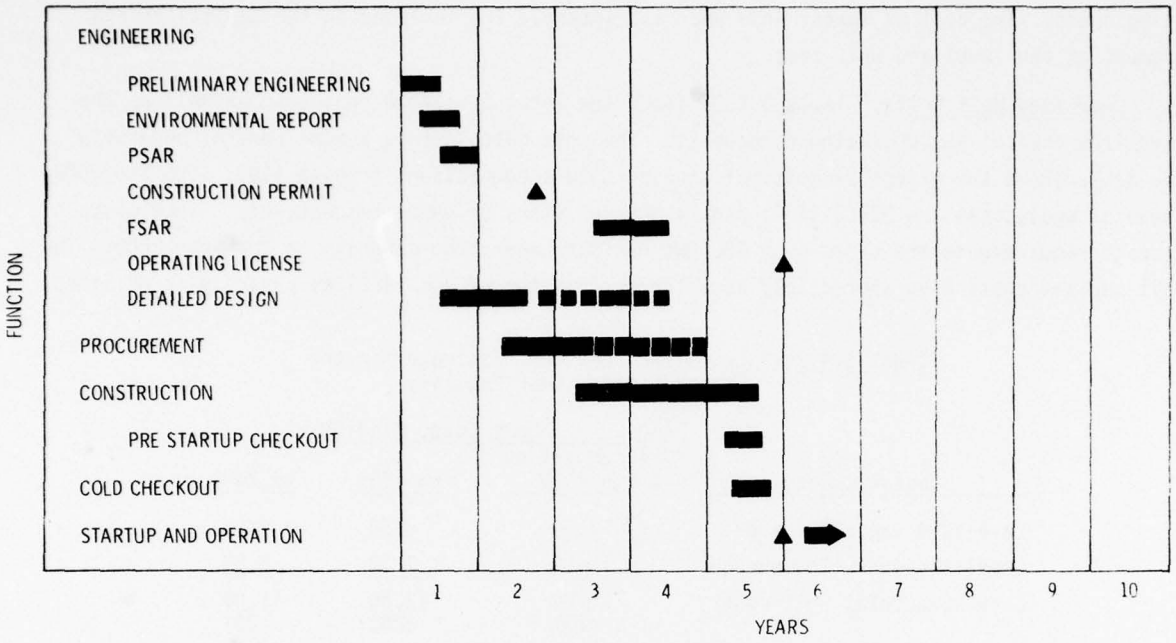


FIGURE 5.4.16. Sealed Storage Cask Facility Engineering, Procurement and Construction Schedule

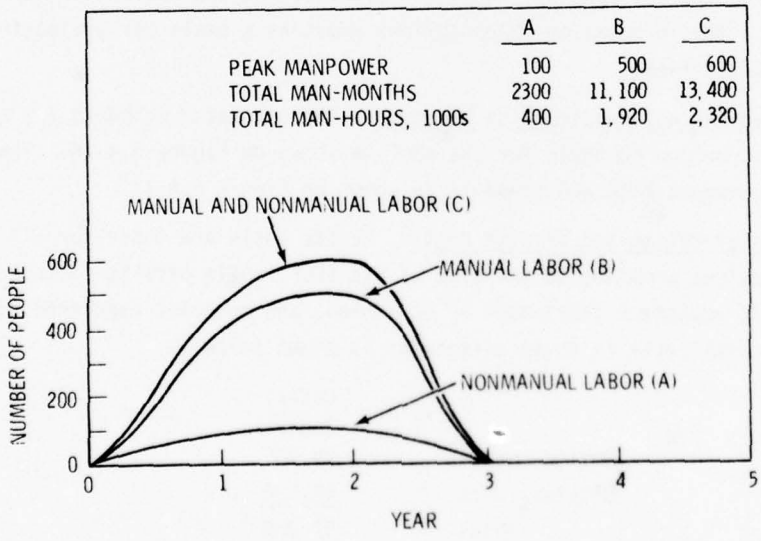


FIGURE 5.4.17. Sealed Storage Cask Facility Construction Labor Force Schedule

Approximately 121 ha (300 acres) are required to be cleared and rough graded for facility installations and storage areas anticipated for storing 20,000 storage units. Approximately 34 ha (85 acres) are required for the initial construction area. An additional 8 ha (20 acres) is needed adjacent to the receiving and assembly facility for construction storage, work yards, temporary buildings and labor parking.

Land requirements for the SSCF consist of:

Facilities (initial construction)	34 ha (85 acres)
(ultimate construction)	121 ha (300 acres)
Property	800 ha (2000 acres)

Water. Water used during the construction period is expected to be about 20,000 m^3 (5.3 x 10^6 gal).

Construction Materials. Major material requirements for facility construction are:

Concrete	13,000 m^3	(17,000 yd^3)
Steel	3,000 MT	(3,300 tons)
Copper (mainly wire and cable)	27 MT	(30 tons)
Zinc	negligible	negligible
Aluminum	18 MT	(20 tons)
Lumber	470 m^3	200 MFBM

Energy. Resources used during construction are:

Propane	265 m^3	(70,000 gal)
Diesel fuel	2,650 m^3	(700,000 gal)
Gasoline	1,900 m^3	(500,000 gal)
Electricity		
Peak demand	830 kW	
Total	1,300,000 kWh	

Transportation Requirements. Approximately 1.6 km (1 mile) of new road is required to provide automobile and truck access from the nearest highway to the site. Approximately 3.2 km (2 miles) of new railroad spur are required for site railroad service.

5.4.2.12 Effects of Fuel Cycle Options

The reference process for SHLW storage assumes reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to SHLW interim storage.

No Recycle. Eliminating the fuel reprocessing operation eliminates the generation of high-level liquid waste. Accordingly, no SHLW storage facilities are required.

Uranium Recycle Only, with Plutonium to a Repository. This alternative is expected to generate about the same amount of SHLW as in the uranium and plutonium recycle case. No significant change in the facility design would be anticipated.

Uranium Recycle Only, with Plutonium to High-level Waste. The impact of this on the storage facility would primarily relate to criticality safety. A criticality safety analysis has been conducted for the interim storage of canisters of solidified high-level waste in a SSCF. The analysis indicates that some form of canister spacing control may be required to assure criticality safety.

Criticality safety control for the waste canisters depends on whether or not the plutonium oxide would concentrate as a result of precipitation and settling during the glass-making operation. If the plutonium is homogeneously distributed, k_∞ is much less than 1, and no additional criticality control is required. However, if the distribution of plutonium is not homogeneous enough, it may be necessary to reduce the mass of plutonium in one canister and/or require geometry and spacing controls. This criticality question cannot be fully resolved until experimental information on the solubility of plutonium in waste glass becomes available.

5.4.3 Physical Protection and Safeguard Requirements for Storage of Solidified High Level Waste (SHLW)

The short-term storage of solidifed high level wastes based on the water basin concept includes the water basin facility as an integral part of the FRP. As such, the physical protection and safeguards descriptions applicable to adjoining operations in the FRP (Section 4.1.4) and to spent fuel interim storage (Section 5.7.9) fully describe the safeguards concerns for this interim step in handling SHLW. These physical protection and safeguards features included concerns for both the uranium-plutonium and uranium only fuel cycles, with the plutonium included with the SHLW.

SHLW, when stored using the sealed storage concept for longer term storage, is neither an attractive nor readily accessible target for theft for subsequent recovery of plutonium for a weapon or as a dispersal threat. In SHLW from the uranium-plutonium fuel cycle, the plutonium content is too low to be a source for sufficient material for a weapon, even if the technical capability required for recovery did exist. Even in the uranium only cycle, with the plutonium in the SHLW, this waste form is not an attractive target for theft. In addition to the significant technical capability required to recover plutonium, the high radiation levels of the waste and the massive enclosures of its reinforced concrete shield significantly reduce the accessibility of this waste in this storage mode.

Sabotage at this facility with the intent of either dispersing material onsite into the environment or permanently disrupting facility operations has a very low probability for success. Because of the vitrified SHLW waste form and its surrounding cask and concrete shield, dispersal through sabotage is not a serious threat to the operations of the facility or to the public. This facility will be manned continuously. Part of the permanent staff will be physical security personnel available for the modest levels of safeguards and physical protection required.

REFERENCES FOR SECTION 5.4

1. Retrievable Surface Storage Facility Alternative Concepts, Engineering Studies, ARH-2888 REV, Atlantic Richfield Hanford Company and Kaiser Engineers, July 1974.

2. Retrievable Surface Storage Facility Conceptual System Design Description, ARH-LD-140, REV, Atlantic Richfield Hanford Company and Kaiser Engineers, March 1977.

3. Alternatives for Managing Wastes from Reactors, and Post-Fission Operations in the LWR Fuel Cycle, ERDA-76-43, Volume 3, SEction 21, U.S. Energy Research and Development Administration, May 1976.

4. Alternatives for Managing Wastes from Reactors, and Post-Fission Operations in the LWR Fuel Cycle, ERDA-76-43, Volume 3, Section 17, U.S. Energy Research and Development Administration, May 1976.

5. Interim Storage of Solidified High-Level Radioactive Wastes, Panel on Engineered Storage, Committee on Radioactive Waste Management, National Research Council, National Academy of Sciences, Washington, DC, 1975.

6. Cohen, J. J., et. al., Determination of Performance Criteria for High-Level Solidified Nuclear Waste, NUREG-0279, Lawrence Livermore Laboratory, Prepared for Nuclear Regulatory Commission, July 1977.

7. Title 10, Code of Federal Regulations, Part 20 (10 CFR 20).

5.5 PLUTONIUM OXIDE STORAGE

5.5 PLUTONIUM OXIDE STORAGE

In the event that spent fuel reprocessing for recycle of uranium alone should prove acceptable and attractive, interim storage of large quantities of plutonium might be necessary until a permanent solution to the use or disposal of plutonium could be defined. Storage of plutonium in the form of a plutonium compound (separate from fission products and other waste products) would afford ease of retrieval should recycle of plutonium as a fuel be adopted in the future.

Current Federal regulations require that plutonium be shipped as a solid chemical compound. Plutonium oxide is currently the preferred chemical form. Plutonium oxide (PuO_2) has a high melting point and good irradiation stability; it is compatible with metals and easy to prepare.[1]

Plutonium could be stored at a fuel reprocessing plant (FRP) or at any large existing Federal nuclear site. Storage at a Federal site would be mandatory if Federal custody of plutonium is required in the future.

In the United States the only large-scale facility built specifically for storing commercial power reactor plutonium was operated by the New York State Atomic and Space Development Authority near Buffalo, New York. The plutonium was stored as plutonium nitrate solution in stainless steel containers that held about 5 kg (11 lb) of plutonium each. This facility is now closed and no plutonium is in storage there. At present, plutonium is stored in small quantities (hundreds of kilograms or less) at several locations around the country. This material is used for weapons and weapons research and for advanced reactor research and development. Storage methods vary and do not meet design needs for large-scale storage.

5.5.1 Interim Plutonium Oxide Storage Facility

The facility described in this section is referred to as the interim plutonium oxide storage facility (IPSF). It will store plutonium oxide that has been separated from uranium and radioactive wastes at an FRP. The plutonium is assumed to be stored at the IPSF until its status as a fuel or waste is resolved.

Storage of large quantities of plutonium oxide must provide for 1) assured protection against the accumulation of a critical mass or self-sustaining chain reaction; 2) removal of radioactive decay heat and, if necessary, hazardous materials generated in the radioactive decay process; 3) radiation shielding; 4) protection against diversion or theft of fissile materials; and 5) protection of the health and safety of the general public and operating personnel.

5.5.1.1 Alternatives for Interim Plutonium Oxide Storage

The design concept selected for the reference facility is based on one proposed by Allied-General Nuclear Services (AGNS) for the Barnwell Plutonium Product Facility (BPPF).[2] The concept involves a vault-type storage structure that will house a concrete storage slab in the floor of the vault. The BPPF could accommodate storage of 500 pressure vessels of the PPP-1 plutonium oxide shipping container design. This container is an AGNS design intended

specifically for the transport and storage of PuO_2 from the BPPF. Each pressure vessel would have a nominal PuO_2 loading of 32 kg (70 lb). Process and operation anomalies could increase the loading up to 40 kg (88 lb) of PuO_2. Further description of the container is given in Section 5.5.1.4. Since the BPPF and the PPP-1 shipping container are currently in the design and development stage, no information is available concerning operational experience with systems, equipment, and components used in the designs.

Concept alternatives to the reference IPSF design involve possible changes in the chemical form of the plutonium product, the type and capacity of the storage containers, and the storage and cooling methods.

Chemical Form. Stored high-burnup fuel plutonium will undergo radioactive decay, thus causing the accumulation of undesired isotopes in the plutonium product. The primary plutonium isotopes contributing to this decay are Plutonium-238 and Plutonium-241. In the event that plutonium recycle proves desirable and acceptable, some reprocessing of the plutonium product may be required before the plutonium can be used. Other chemical forms of plutonium, particularly solid forms of plutonium nitrate, may be more practicable than PuO_2 powder for this reprocessing step. Research and development is currently in progress on several such chemicals to determine if an alternative chemical form can be produced simply and economically and can be stored and shipped safely.[3] Should these alternative chemical forms prove acceptable, the plutonium storage facility design could be altered, if necessary, to accommodate the new compound.

Storage Container. Several types of containers other than the reference container are available for storing the plutonium products. These include the L-10, the 6M, and the LLL-1 shipping containers.[4] The L-10 container holds up to 16 kg (35.3 lb) of plutonium while the other two containers hold up to 4.5 kg (9.9 lb) of plutonium. Use of these lower capacity containers would allow simpler methods of plutonium storage and cooling than those used in the reference design but would have the disadvantage of requiring a larger number of containers and a larger storage area than necessary for the reference design.

Storage and Cooling Method. One desirable characteristic not present in the reference design is passive cooling of the storage containers. Forced convection cooling of reference storage containers is required because of the large plutonium loading. Passive (thermal convection) cooling could be achieved by using one of the lower capacity storage containers described above. This storage method would be simpler and more reliable in design but would be harder to shield and would require a larger building to accommodate a capacity equivalent to the reference design.

Another desirable storage characteristic is the elimination of container maintenance once the container is in storage. Any maintenance that requires removal of the container from its storage location (except for off-normal or emergency conditions) would complicate operations and increase the likelihood of accidents. Welding the storage container lids after closure would eliminate the need for periodic seal maintenance; however, some maintenance would still be required to reduce gas pressure (He, H_2, and O_2) and explosive gas (H_2 and O_2)

buildup caused by radiolytic decomposition of the plutonium product. Alternatively, designing the container to withstand high pressures and all consequences of internal explosion would eliminate the need for routine container maintenance. Because of uncertainties in the actual container specifications, the reference design containers are assumed to require periodic venting and seal maintenance.

5.5.1.2 Design Basis for the Interim Plutonium Oxide Storage Facility

Three variations of the reference facility are described and analyzed:

1. A 30-MT PuO_2 storage facility built in close proximity to the FRP. This facility holds 1000 storage containers and provides a modular design upon which larger limits may be based. Nominal PuO_2 loading for this facility is 32 MT (35 tons) PuO_2, with a maximum capacity of 40 MT (44 tons) PuO_2. This facility is hereafter referred to as the 30-MT FRP IPSF. The normal radioactivity inventory in a full 30-MT PuO_2 storage unit is shown in Table 5.5.1.

TABLE 5.5.1. Radioactivity Inventory Stored in a 30-MT PuO_2 Storage Unit

Actinides	Total Inventory, Ci[a]
^{239}Pu	1.0×10^6
^{241}Pu	3.5×10^8
Other Pu	1.2×10^7
All other actinides	5.8×10^5
Total	3.6×10^8

a. For 32 MT of PuO_2 (product of 1.7 years operation of reference FRP) in 1000 storage containers; based on Table 3.3.16, average of 2.5 years out of reactor.

2. A 200-MT PuO_2 storage facility built in close proximity to the FRP. This unit holds 6000 storage containers and provides capacity to store about 10 years' worth of PuO_2 produced by the reference FRP. Nominal PuO_2 loading for the facility is 192 MT (210 tons) PuO_2, with a maximum capacity of 240 MT (265 tons) PuO_2. The radioactivity inventory is approximately six times that of a 30-MT unit. This facility is hereafter referred to as the 200-MT FRP IPSF.

3. A 200-MT (220 ton) PuO_2 storage facility built on a separate site as an independent facility. This facility also holds 6000 containers and is hereafter referred to as the 200-MT independent interim plutonium oxide storage facility (IIPSF). The PuO_2 inventory is the same as for item 2.

Locating the IPSF in close proximity to the FRP will allow sharing of utilities, services, and personnel and will minimize plutonium transportation. The IIPSF will have to provide its own utilities, services, and personnel.

The following assumptions were made in the design of the reference facility:

- The plutonium product used in this analysis will contain high-exposure plutonium. The reference composition is shown in Table 3.3.16.
- All required functions, such as cooling, ventilation, and power, will be ensured by back-up systems to maintain acceptable operating conditions at all times.
- The design of the three IPSFs is based on safety considerations, ease of storage, and ease of retrieval when required.
- Plutonium will be contained by multiple barriers that are designed for minimum dependence on people and devices.
- The storage container will be the pressure vessel of the AGNS PPP-1 shipping container. Use of a shipping container component eliminates the need for a separate storage container and simplifies storage facility operations.
- The reference design will be a vault type of storage similar in design to the plutonium oxide storage for the BPPF.
- IPSF design will be shown to be adequate from a safety standpoint. Optimization of parameters such as container storage spacing, cooling annulus spacing, and radiation shielding thickness are desirable from a cost standpoint but will not be considered in this analysis.
- The range of all safety-related instrumentation will be wide enough to include system safety setpoints (error conditions) as well as normal operating ranges.
- The facility shall have the necessary people and equipment to defend against a terrorist attack.

5.5.1.3 Operation of the Interim Plutonium Oxide Storage Facility

An operations flow diagram is shown in Figure 5.5.1. Upon arrival at the IPSF, the PPP-1 shipping container (pressure vessel and overpack) is removed from the carrier truck by an electric fork-lift truck. The shipping container is brought into the IPSF via the transfer air lock and placed in the entrance chamber to the inspection and transfer cell. Operating personnel remove the overpack lid, and the container is lifted to the entrance port. A power manipulator, remotely controlled from outside the cell, removes the entrance port plug and lifts the PPP-1 pressure vessel into the inspection and transfer cell. The pressure vessel is then placed in the maintenance rack for inspection. This same rack is used for all pressure vessel maintenance (inspections, repairs, venting, etc.).

The PPP-1 pressure vessel (now the IPSF storage container) is inspected and decontaminated as necessary. The power manipulator is then used to remove the exit port plug and transfer the container to the shielded transfer cask positioned below the exit port. Another electric fork-lift truck moves the container in the transfer cask to the cask transfer gallery.

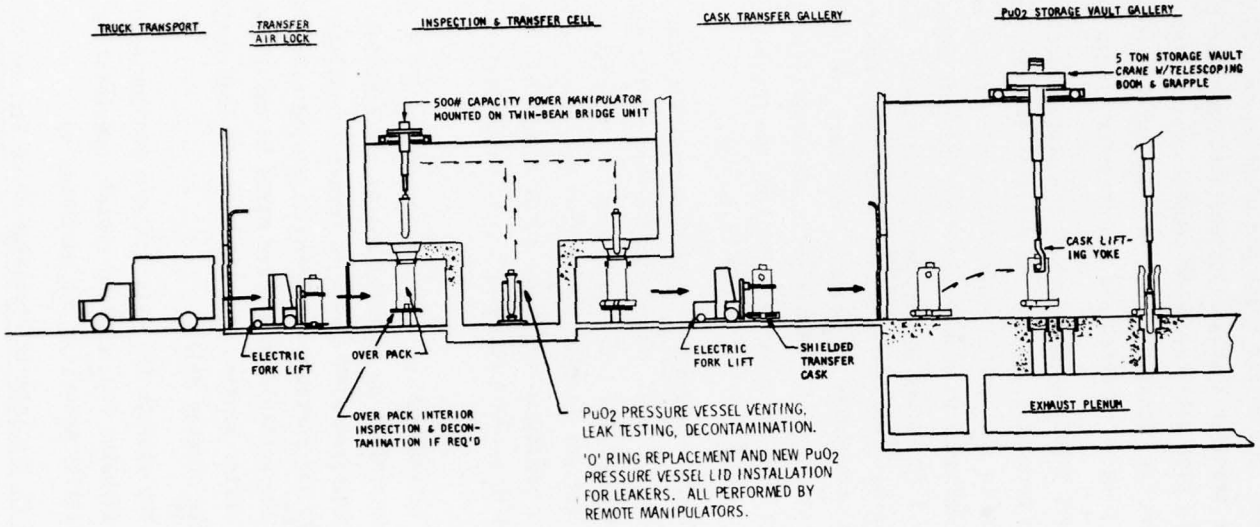


FIGURE 5.5.1. Interim Plutonium Oxide Storage Facility Operations Flow Diagram

The pressure is equalized between the PuO_2 storage vault and the transfer gallery, and the vault door is opened. The transfer cask is then placed on the storage vault floor using the fork-lift truck. The vault door is resealed and leak tested, and storage vault negative pressure is reestablished. The bridge crane and grapple, controlled remotely from the IPSF control room, engage the transfer cask and storage container and position them over an empty storage hole. The shield plug will have been removed previously with the crane. The storage container is lowered from the transfer shield into the storage hole and the crane grapple disengaged. The shield plug is replaced and the transfer shield stored.

During all operations involving movement of the storage containers within the PuO_2 storage vault gallery, operating personnel observe the position and attitude of the container through a shielded viewing window in the control room. All tools, fixtures, and equipment in the storage vault have been designed to enable operation and maintenance with a minimum of radiation exposure. The fork-lift trucks may be used in the storage vault for back-up and limited emergency handling if the building crane is out of service. Administrative controls will ensure that at all times only a safe number of storage containers are handled in the storage vault or the inspection and transfer cell. Removal of a container from a storage location would be a reverse operation. The IPSF has a maximum handling and processing capacity of eight to ten containers (approximately 320 kg of PuO_2) in a 24-hr day.

Storage of PuO_2 over an extended period produces 1) molecular oxygen and hydrogen gases from the radiolytic decomposition of water not removed from the plutonium product, and 2) elemental helium gas from the alpha radiation decay of plutonium and plutonium daughter products. These gases will collect in the storage containers and increase the container pressures. Container venting may be required to limit pressures resulting from gas buildup and container temperature variation and to prevent accumulation of an explosive concentration of hydrogen and oxygen.

Venting operations, if required by final design of the PPP-1 container, will be performed at regular intervals as determined by calculations of the container pressure and gas contents. The storage container is equipped with a vent to remove accumulated gases from the container. The shield plug is removed and portable shielding is placed over the storage hole. The container is then placed in the portable shield and moved to the inspection and transfer cell for venting and maintenance. After venting, the container is leak tested, checked for contamination, and returned to the storage hole.

Normal operation of the storage facility includes monitoring of temperatures, pressures, and air flows associated with the PuO_2 cooling system; preventative and corrective maintenance on facility equipment; facility security; and housekeeping.

5.5.1.4 Description of the Interim Plutonium Oxide Storage Facility

Each of the three IPSFs consists of a PuO_2 storage vault (storage slab, storage vault gallery, and ventilation exhaust plenum); shipping cask and storage container receiving, handling, and inspection area; ventilation system area (housing ventilation filters, blowers, and associated ductwork); and personnel accommodation area (control room, offices, restrooms, etc.).

General Description. The structure that surrounds the entire IPSF, except for the office areas and the security office area, is Category I. It is designed to withstand design basis earthquakes, hurricane winds, tornados, floods, and tornado-generated missiles without breach of integrity in accordance with NRC Regulatory Guide requirements. The storage slab is an integral part of the IPSF building and meets the same structural design requirements.

Systems and equipment important to safety are either protected from or designed to withstand any postulated credible earthquakes, hurricanes, tornados, floods, or other natural phenomena. The IPSF is also designed to minimize the probability of fire or explosion and, in the event of such occurrences, to minimize their potential effects.

The storage vault is a low leak-rate room (less than 200% per 24 hr at 0.25 in. H_2O) and will normally operate at -0.15 in. H_2O.

30-MT FRP IPSF. A plot plan for the 30-MT FRP IPSF is shown in Figure 5.5.2. The facility is adjacent to the FRP and connected by an access road. Figures 5.5.3 through 5.5.7 illustrate the various areas within the IPSF.

200-MT FRP IPSF. Figure 5.5.8 is a plot plan for the 200-MT FRP IPSF. This facility also adjoins the FRP and is connected by an access road. Table 5.5.2 lists the equipment in the facility and provides a key to equipment locations for the facility layouts shown in Figures 5.5.9 through 5.5.16.

200-MT IIPSF. A plot plan for the 200-MT IIPSF is shown in Figure 5.5.17. The facility does not adjoin the FRP and thus has utility features (e.g., water, electricity, and steam) independent of the FRP. An access road connects the IIPSF to a highway assumed to be 3 miles distant. Details of the facility layout are shown in Figures 5.5.18 and 5.5.19. Areas of the 200-MT IIPSF corresponding to Figures 5.5.11 through 5.5.16 are identical to those drawn for the 200-MT FRP IPSF and are not repeated here.

Storage Slab. The storage slab provides radiation shielding, proper storage container spacing for criticality control, and structural support for the storage array. The storage slab configuration is shown in Figure 5.5.20. Each storage hole houses a single storage container positioned by guides and spacers to permit ventilation air flow from the storage slab floor down the container to the exhaust plenum. The storage holes are spaced 0.76 m (30 in.) center-to-center for criticality safety. The slab is 2.1 m (7 ft) of reinforced concrete and is an integral part of the building structure. A concrete plug is provided to lower radiation levels at the slab floor. The storage hole is lined with stainless steel pipe. Instruments are provided to monitor coolant air temperature and activity.

Storage Container. The storage container used at the IPSF is the PPP-1 plutonium shipping container, which includes the pressure vessel and canisters. This container is shown in Figure 5.5.21. Filtered vents are provided to allow gases generated in the canisters to pass into the pressure vessel. The pressure vessel is made of stainless steel, holds four canisters, and is designed to withstand 230 psig internal pressure. The pressure vessel is equipped with a manual vent to allow controlled release of gas pressure.

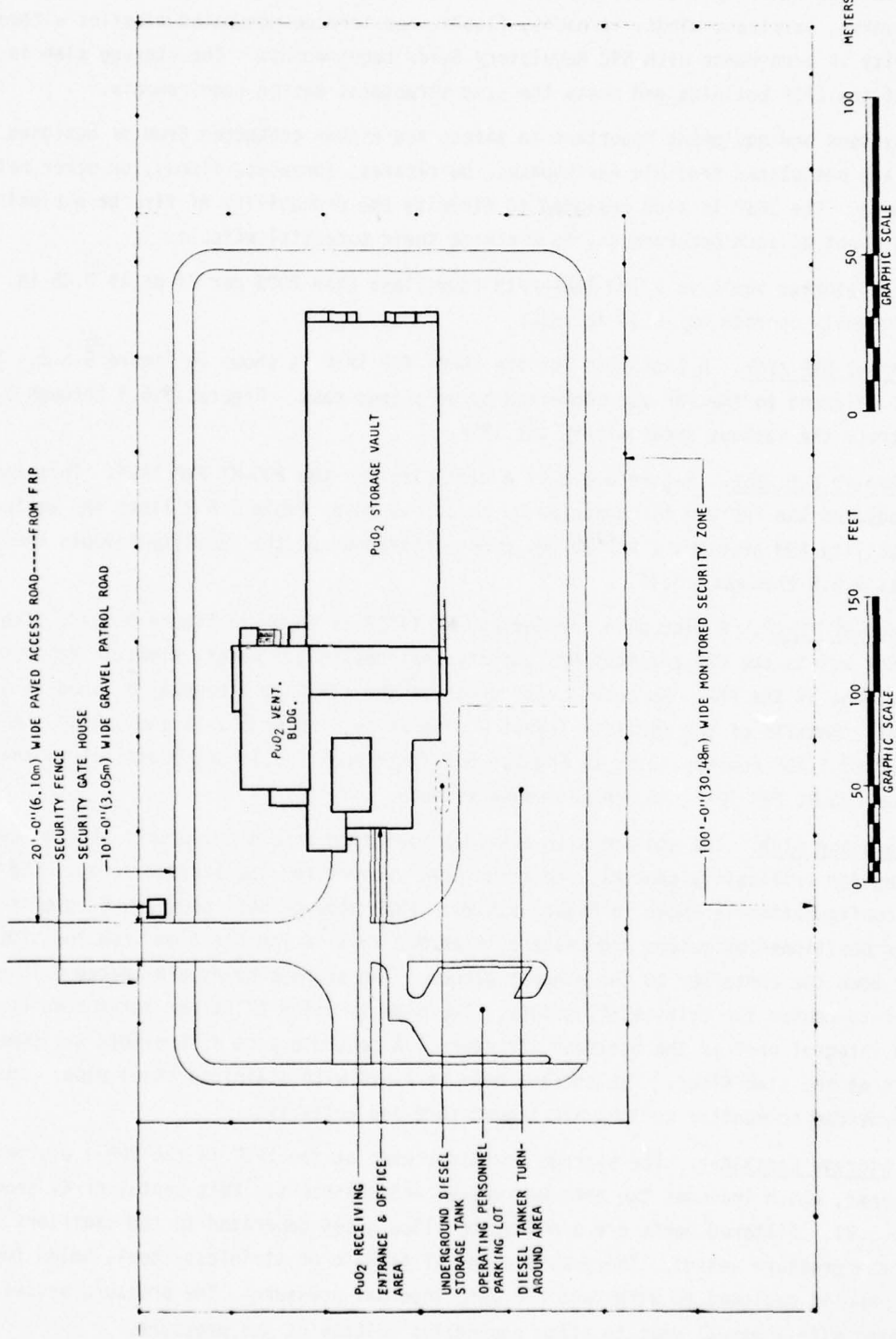


FIGURE 5.5.2. Plot Plan for the 30-MT Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant

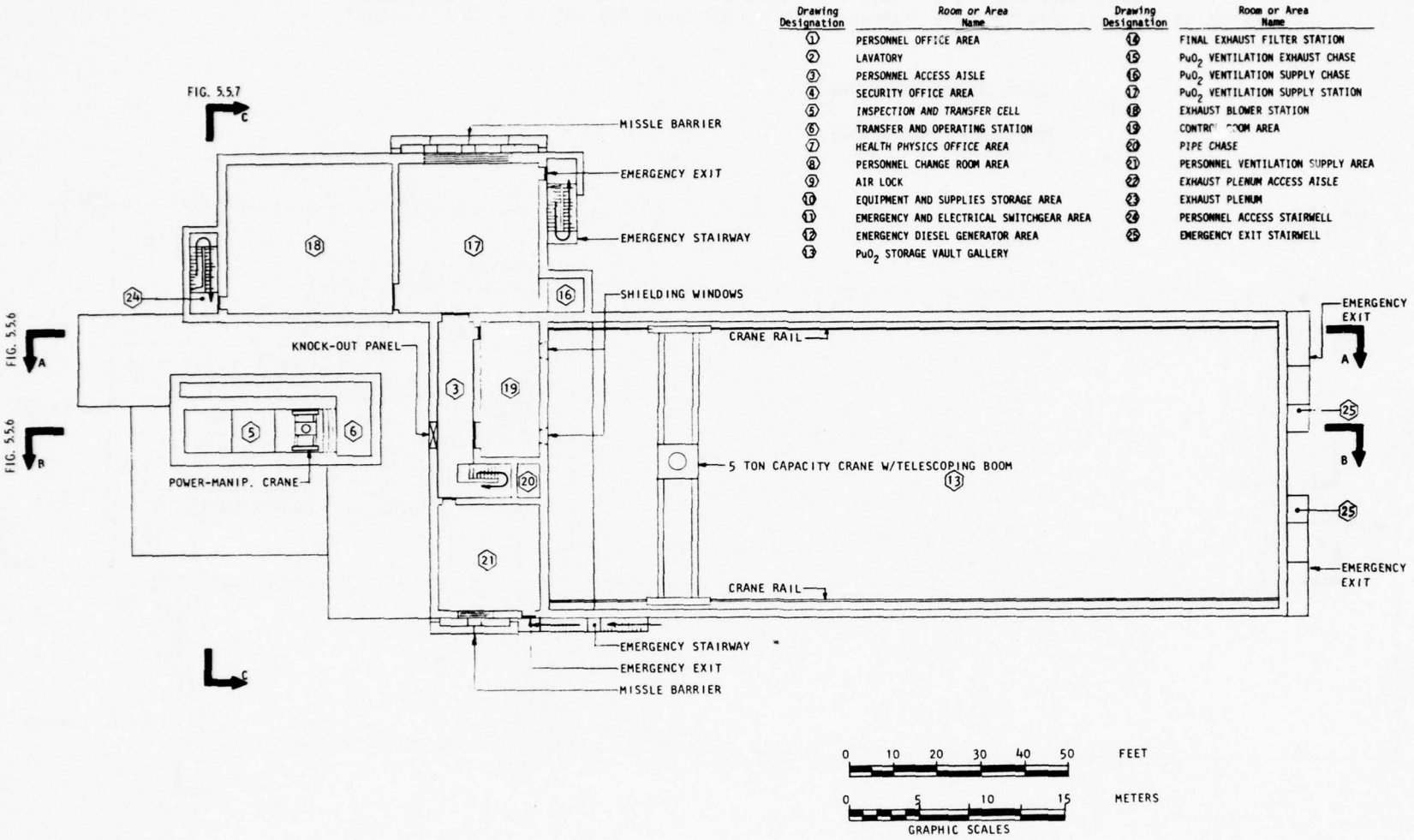


FIGURE 5.5.3. Second Floor Plan for the 30-MT Fuel Reprocessing Plant Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant

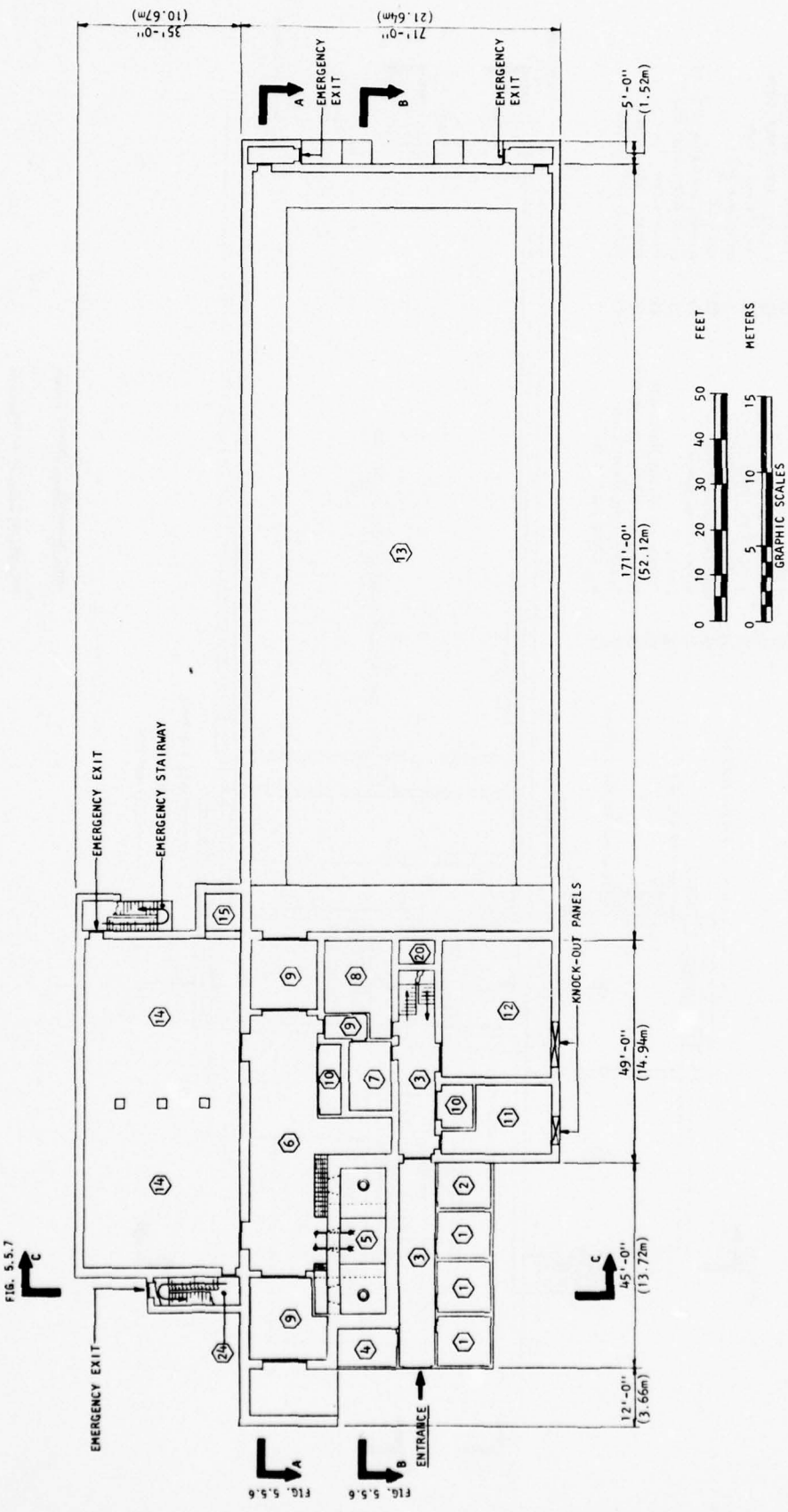


FIGURE 5.5.4. Plan for the 30-MT FRP Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant, at Grade (See Figure 5.5.3 for number key.)

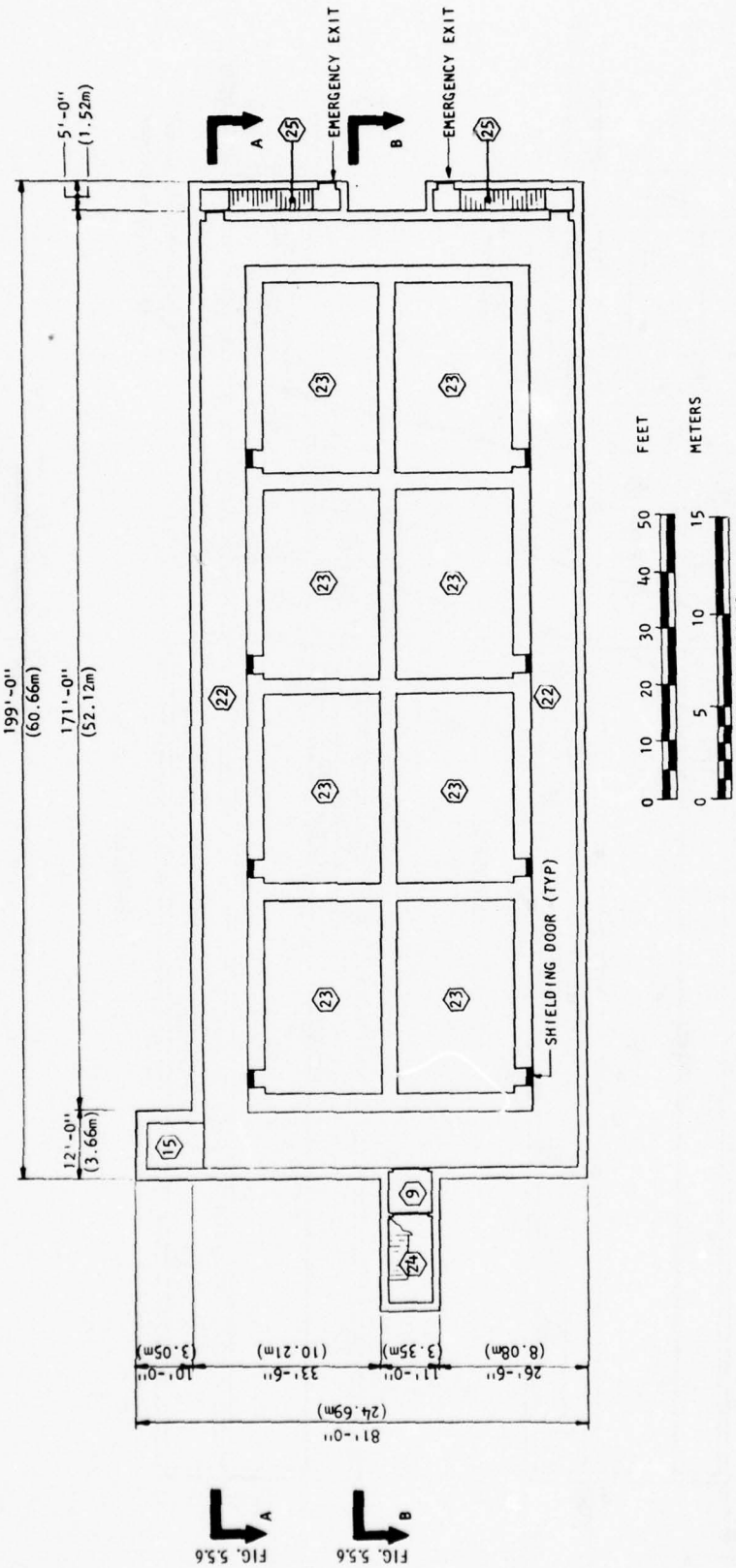


FIGURE 5.5.5. Plan for the 30-MT FRP Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant, Below Grade (See Figure 5.5.3 for number key)

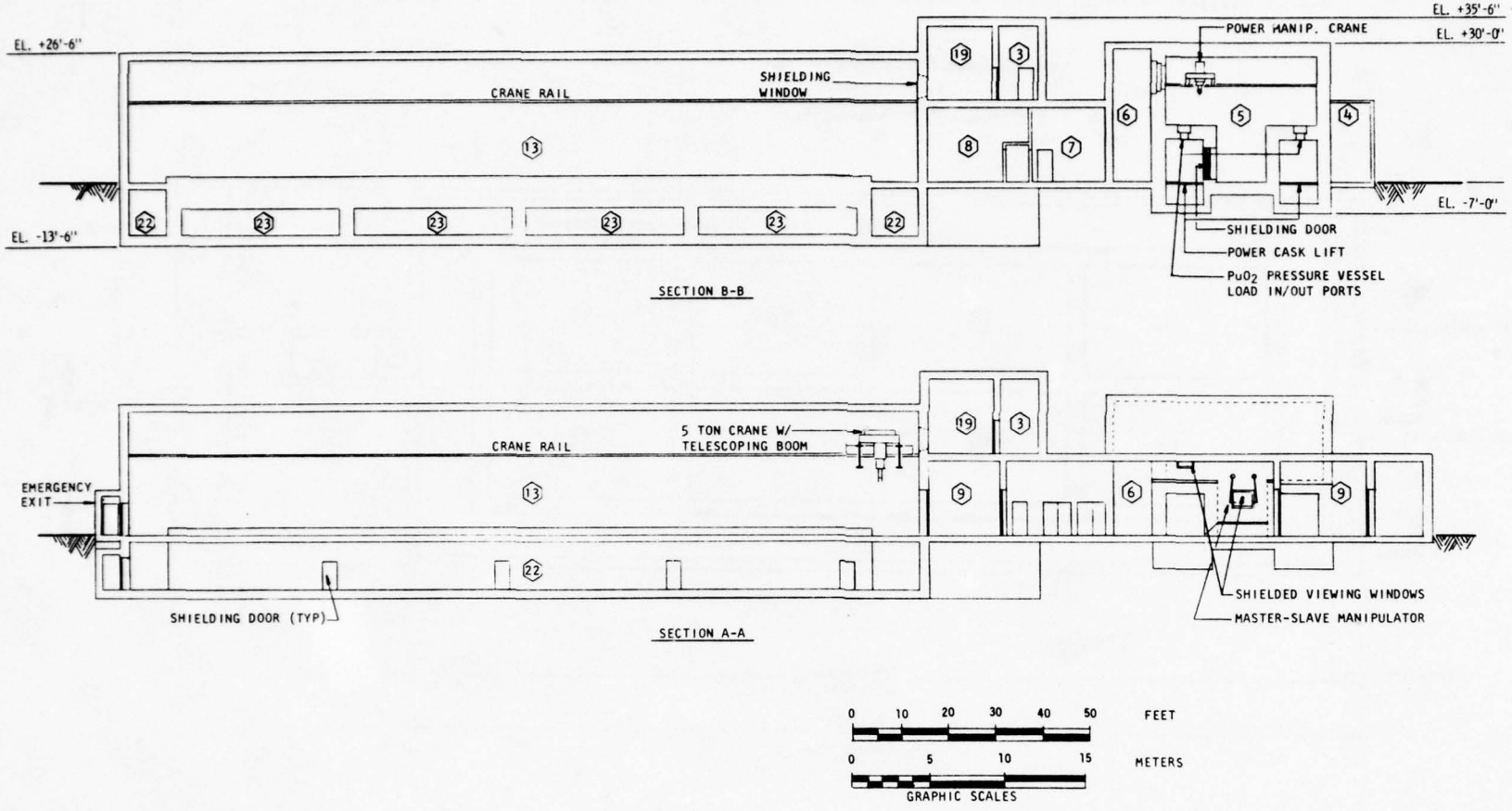


FIGURE 5.5.6. Plan for the 30-MT FRP Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant, Sections A-A and B-B (See Figure 5.5.3 for number key.)

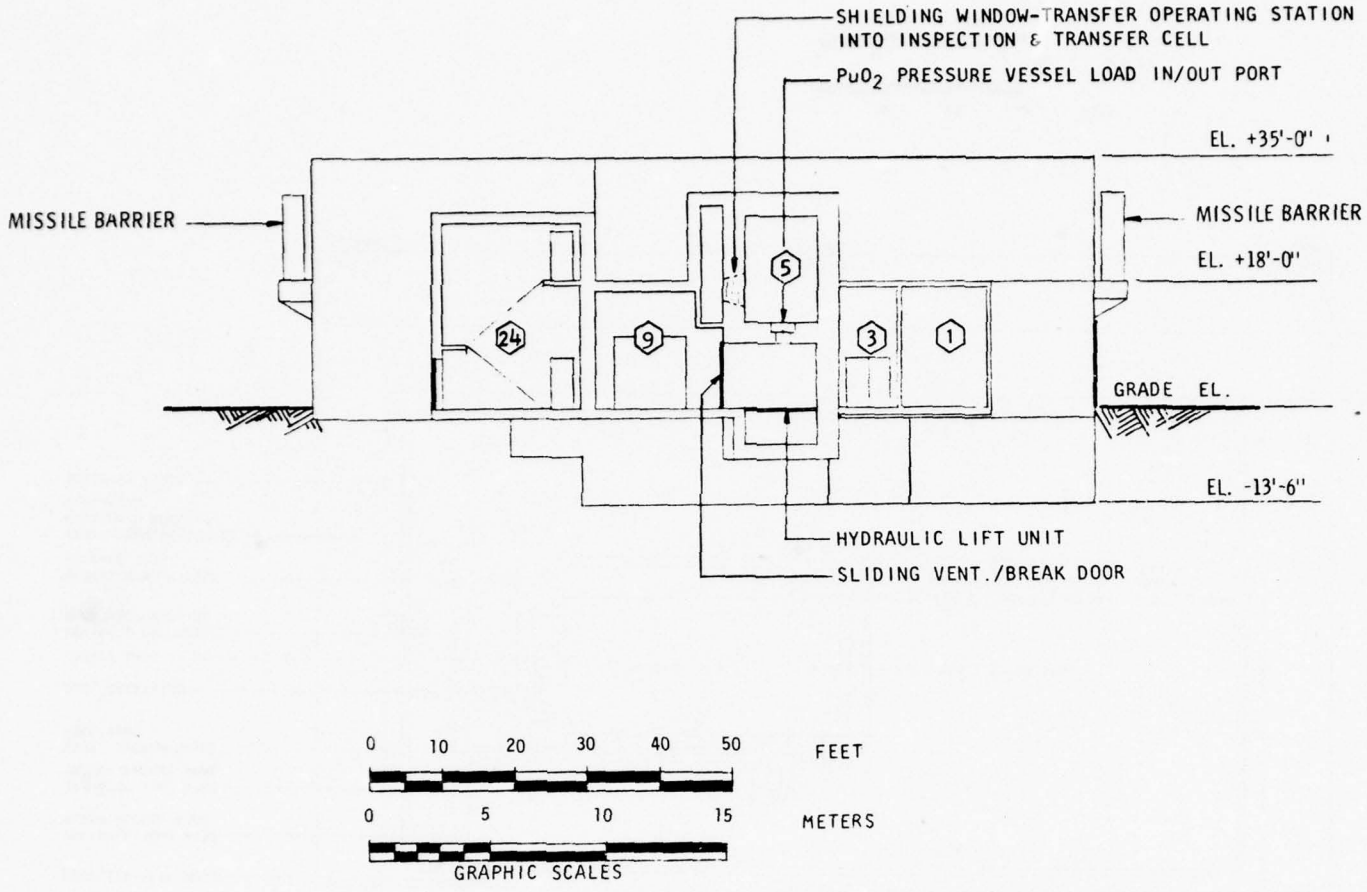


FIGURE 5.5.7. 30-MT Interim Plutonium Oxide Storage Facility Plant at the Fuel Reprocessing Plant, Section C-C (See Figure 5.5.3 for number key.)

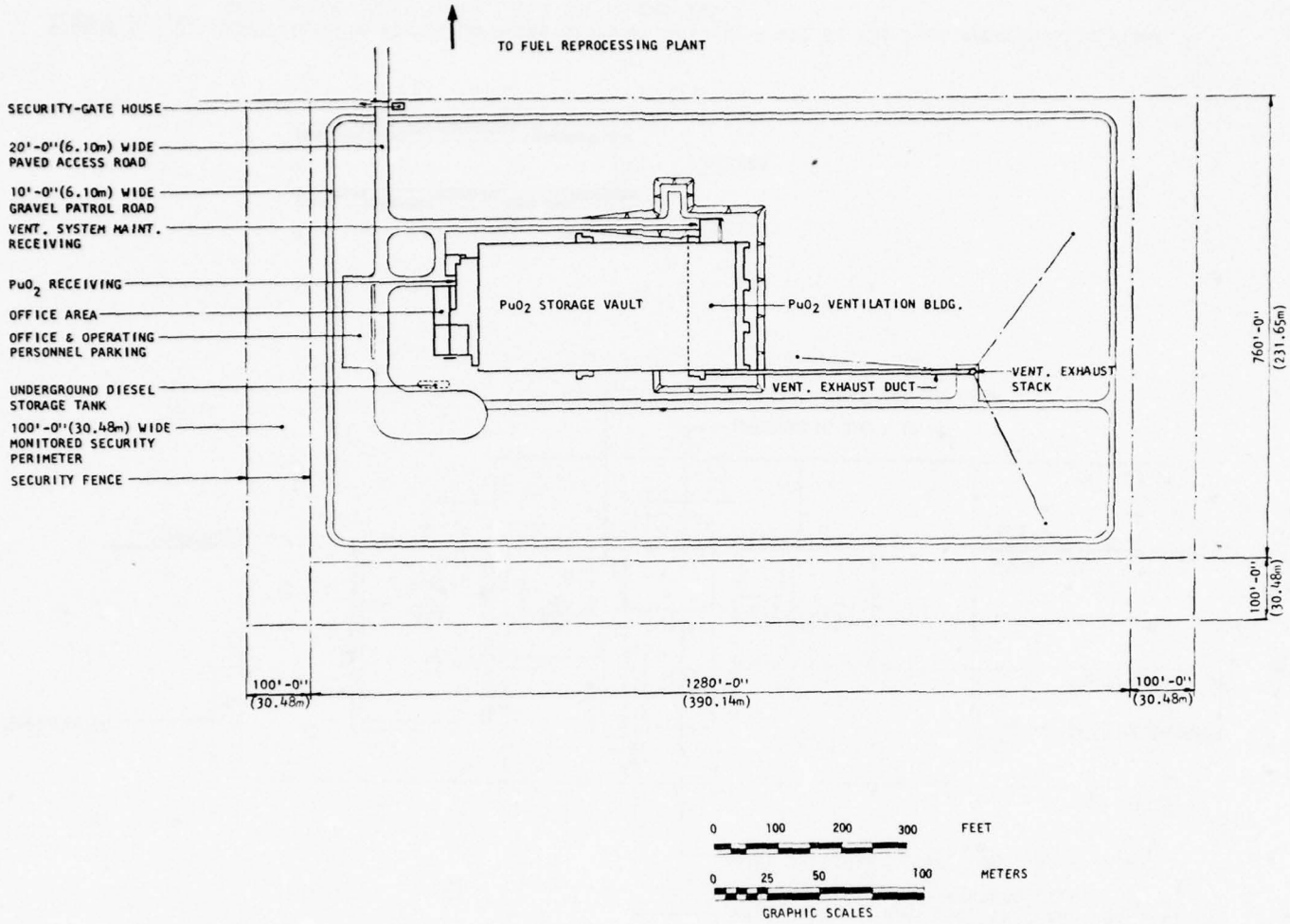


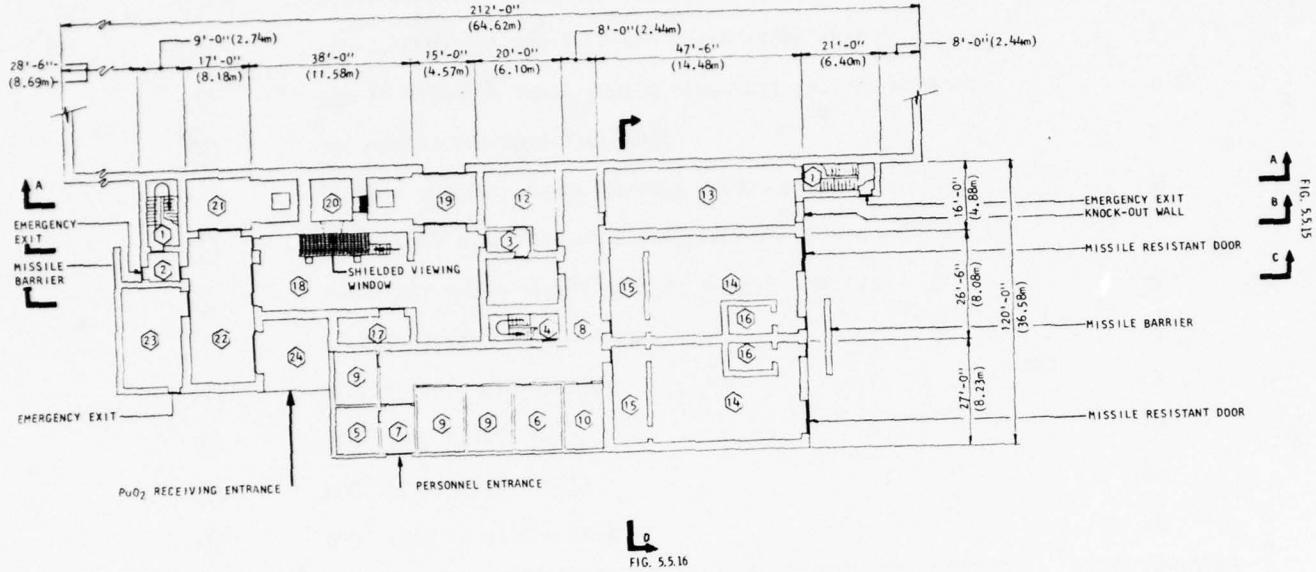
FIGURE 5.5.8. Plot Plan for the 200-MT Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant

TABLE 5.5.2. Equipment in the 200-MT Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant

Drawing Designation	Equipment Name	Number of Units Required
①	PuO_2 initial filter unit	48
②	PuO_2 final filter unit	60
③	PuO_2 HVAC supply unit	6
④	PuO_2 exhaust blower unit	9
⑤	Personnel HVAC supply unit	2
⑥	5-ton twin-beam bridge unit with radio control	3
⑦	5-ton twin-beam underhung trolley with telescoping boom grapple and cask power takeoff (radio control)	2
⑧	1500-kW diesel generator unit	2
⑨	500-lb capacity power manipulator unit (bridge mounted)	1
⑩	100-lb capacity master-slave manipulator unit	1
⑪	2-ton capacity hydraulic lift unit (PuO_2 cask)	2

Drawing Description	Room or Area Name
1	EMERGENCY EXIT STAIRWELL
2	EMERGENCY EXIT AIR LOCK
3	PERSONNEL ACCESS AIR LOCK
4	PERSONNEL ACCESS STAIRWELL
5	SECURITY OFFICE
6	LAVATORY
7	ENTRANCE LOBBY
8	PERSONNEL ACCESS AISLE
9	OFFICE
10	STORAGE ROOM
11	HEALTH PHYSICS OFFICE
12	PERSONNEL CHANGE ROOM
13	ELECTRICAL SWITCHGEAR AREA
14	EMERGENCY ELECTRICAL SWITCHGEAR AREA
15	EMERGENCY ELECTRICAL DIESEL GENERATOR AREA
16	DIESEL STORAGE DAY TANK AREA
17	STORAGE STATION
18	TRANSFER OPERATING STATION
19	CASK TRANSFER GALLERY
20	INSPECTION AND TRANSFER CELL
21	OVERPACK UNLOADING AND LOADING STATION
22	TRANSFER AIR LOCK
23	MAINTENANCE SHOP AREA
24	LOADING DOCK
25	VERTICAL PIPE CHASE
26	PERSONNEL VENTILATION SUPPLY AREA
27	CONTROL ROOM AREA
28	CONTROL ROOM ANNEX AREA
29	POWER-MANIPULATOR MAINTENANCE CELL
30	PuO_2 STORAGE VAULT GALLERY
31	PuO_2 EXHAUST PLENUM
32	PuO_2 EXHAUST PLENUM ACCESS AISLE
33	PuO_2 EXHAUST BLOWER STATION
34	PuO_2 VENTILATION SUPPLY STATION
35	ELEVATOR WELL
36	MAINTENANCE AND SUPPLY VEHICLE AIR LOCK
37	PuO_2 EXHAUST FILTER STATION
38	AIR AND VACUUM SUPPLY AREA
39	CHILL WATER STATION

FOR CONT. SEE FIGURE NO. 5.5.11



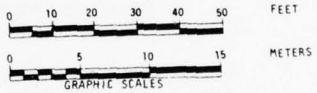


FIGURE 5.5.9. Plan for the 200-MT Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant, Plutonium Oxide Receiving Area at Grade

FOR CONT. SEE FIGURE NO. 5.5.11

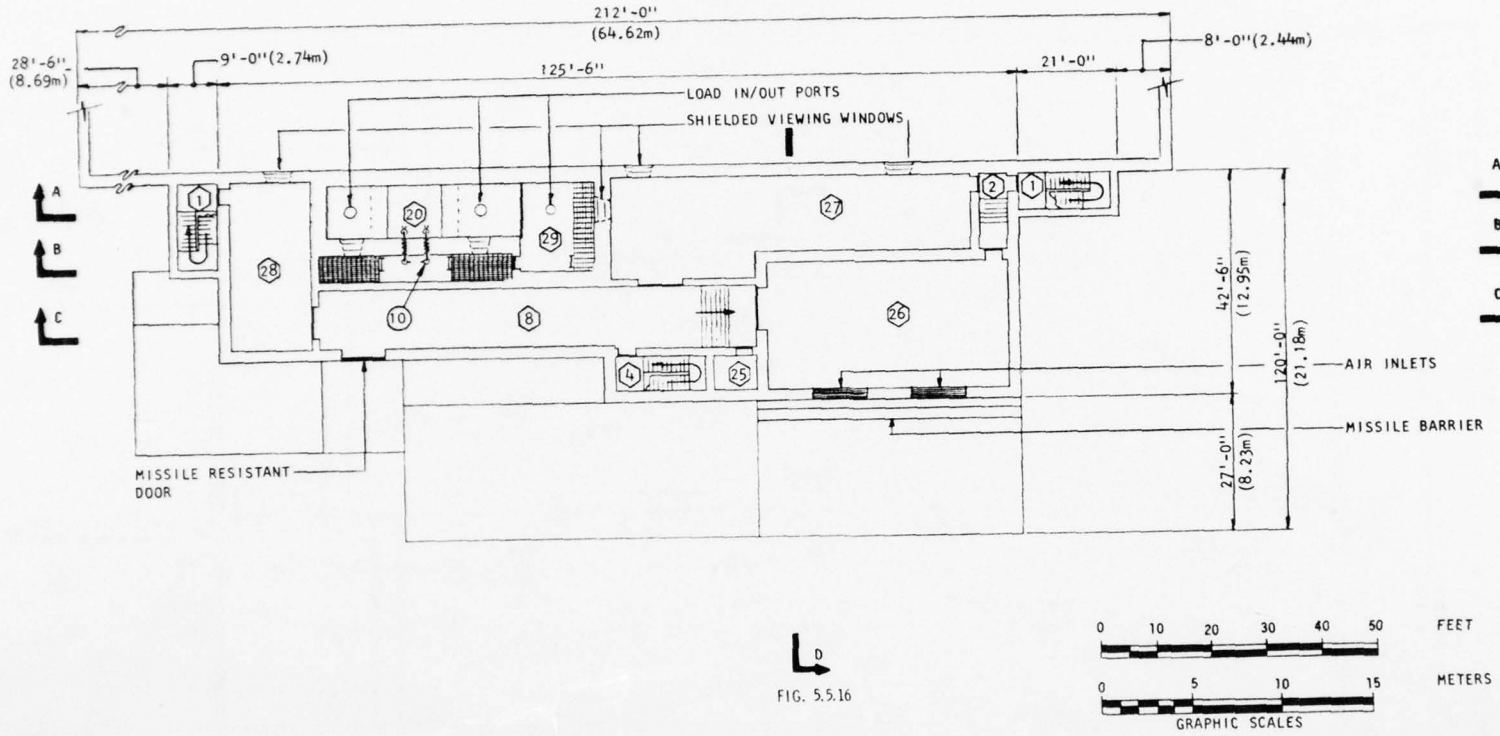


FIGURE 5.5.10. Plan for the 200-MT Interim Plutonium Oxide Storage Facility, Second Floor of the Plutonium Oxide Receiving Area (See Figure 5.5.9 for number key.)

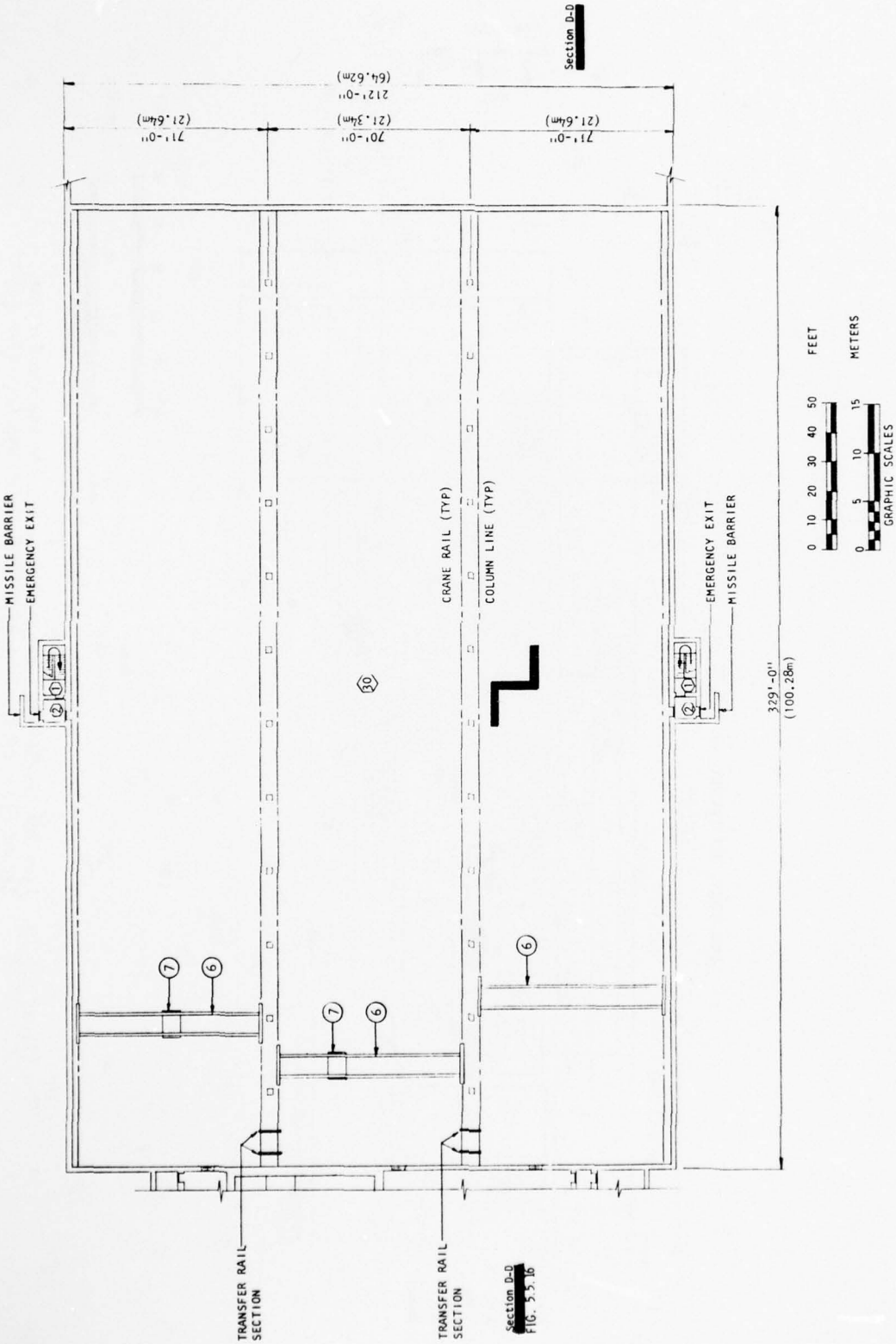


FIGURE 5.5.11. Plan for the 200-MT Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant, Plutonium Storage Vault at Grade (See Figure 5.5.9 and Table 5.5.1 for number keys.)

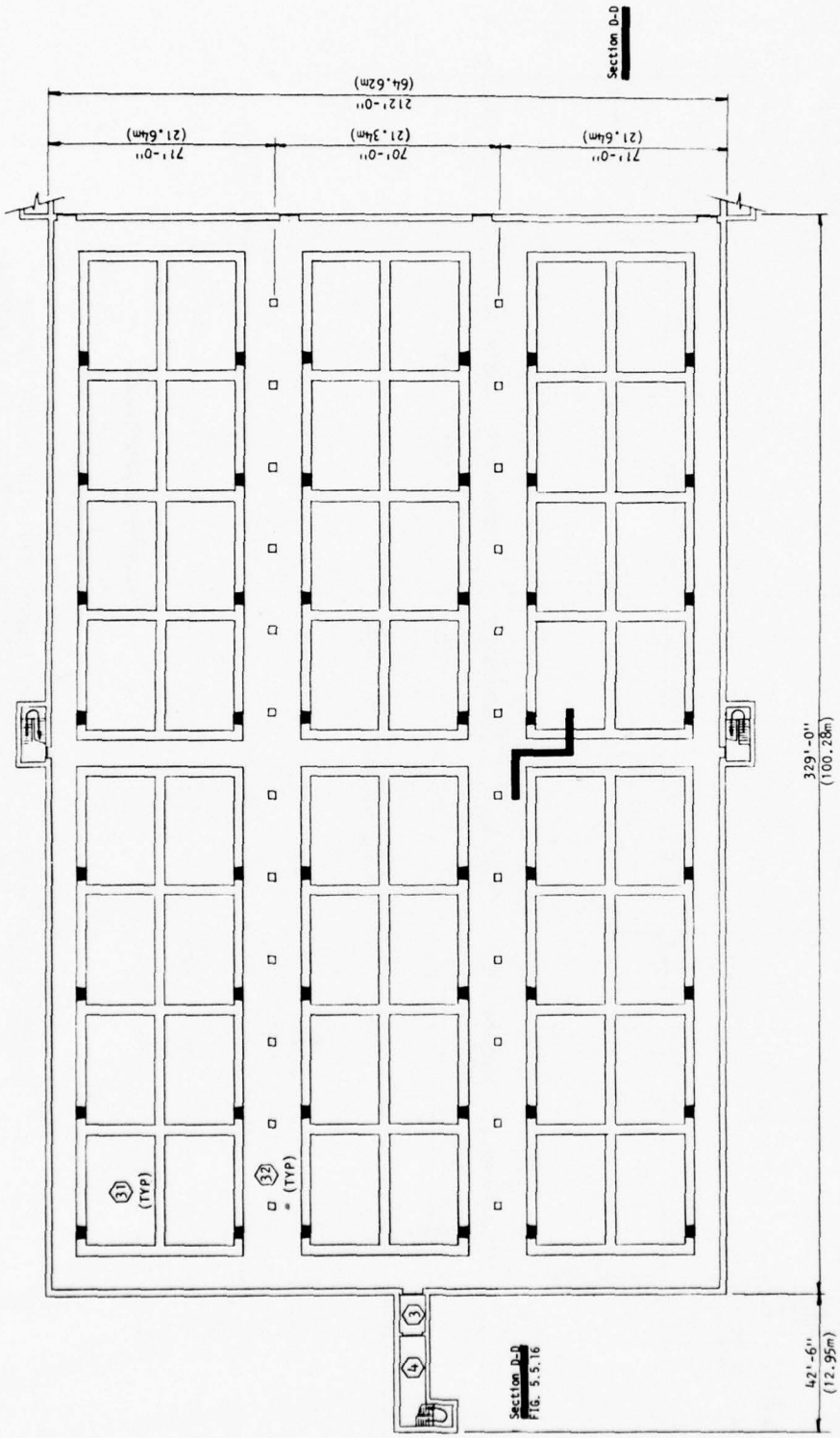


FIGURE 5.5.12. Plan for the 200-MT Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant, Plutonium Storage Vault Below Grade (See Figure 5.5.9 for number key.)

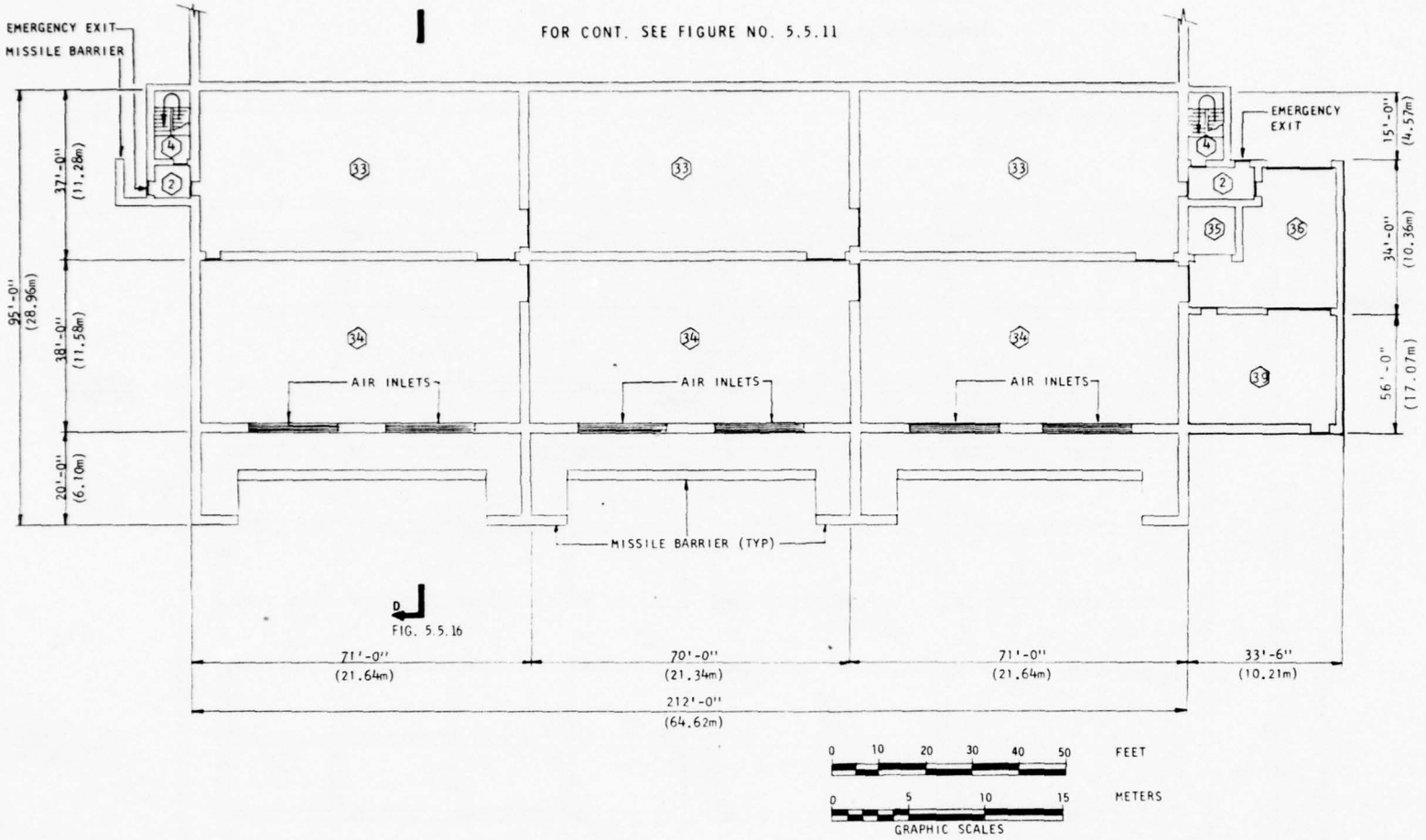


FIGURE 5.5.13. Plan for the 200-MT Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant, Vault Ventilation Area at Grade (See Figure 5.5.9 for number key.)

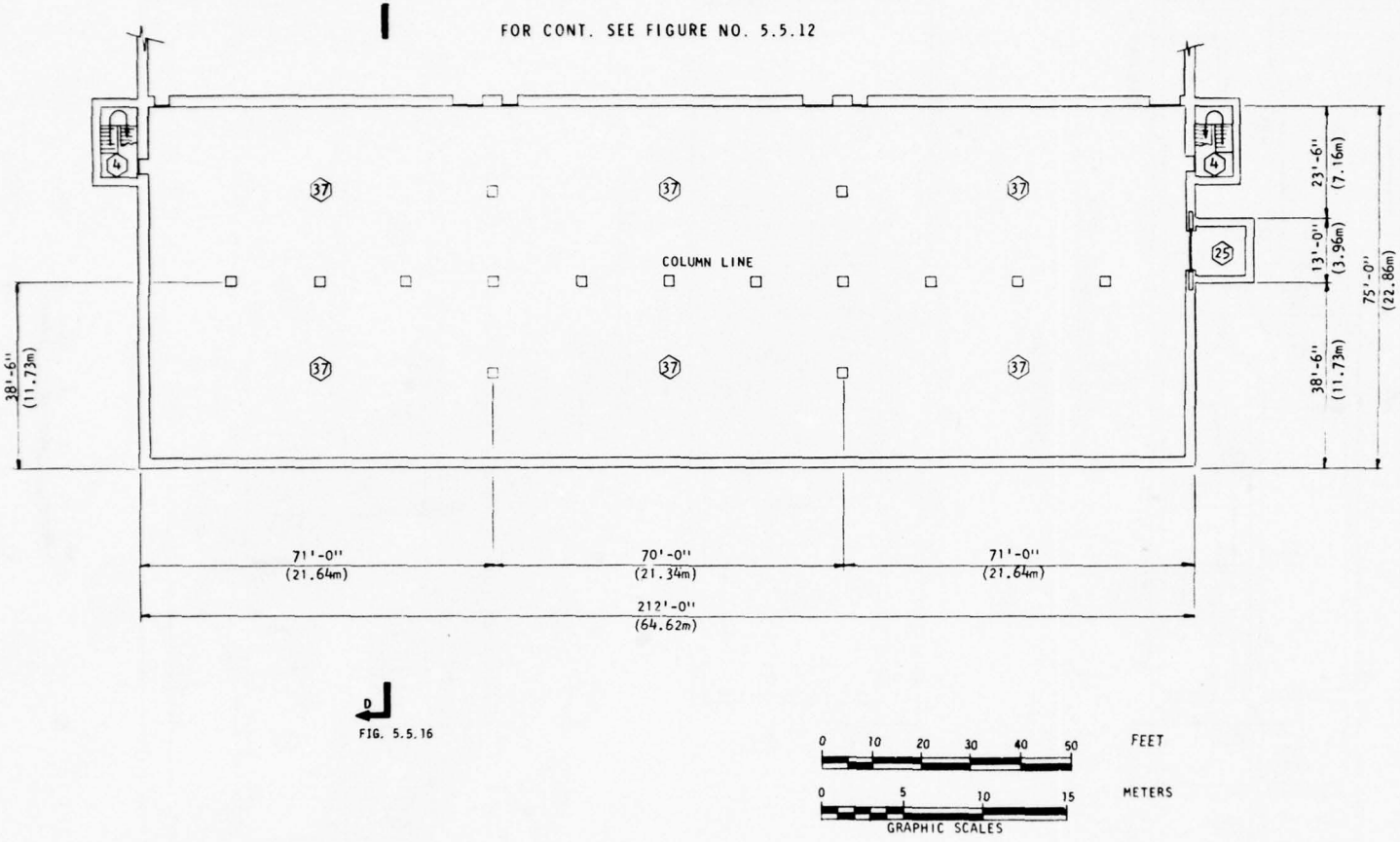


FIGURE 5.5.14. Plan for the 200-MT Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant, Vault Ventilation Area Below Grade (See Figure 5.5.9 for number key.)

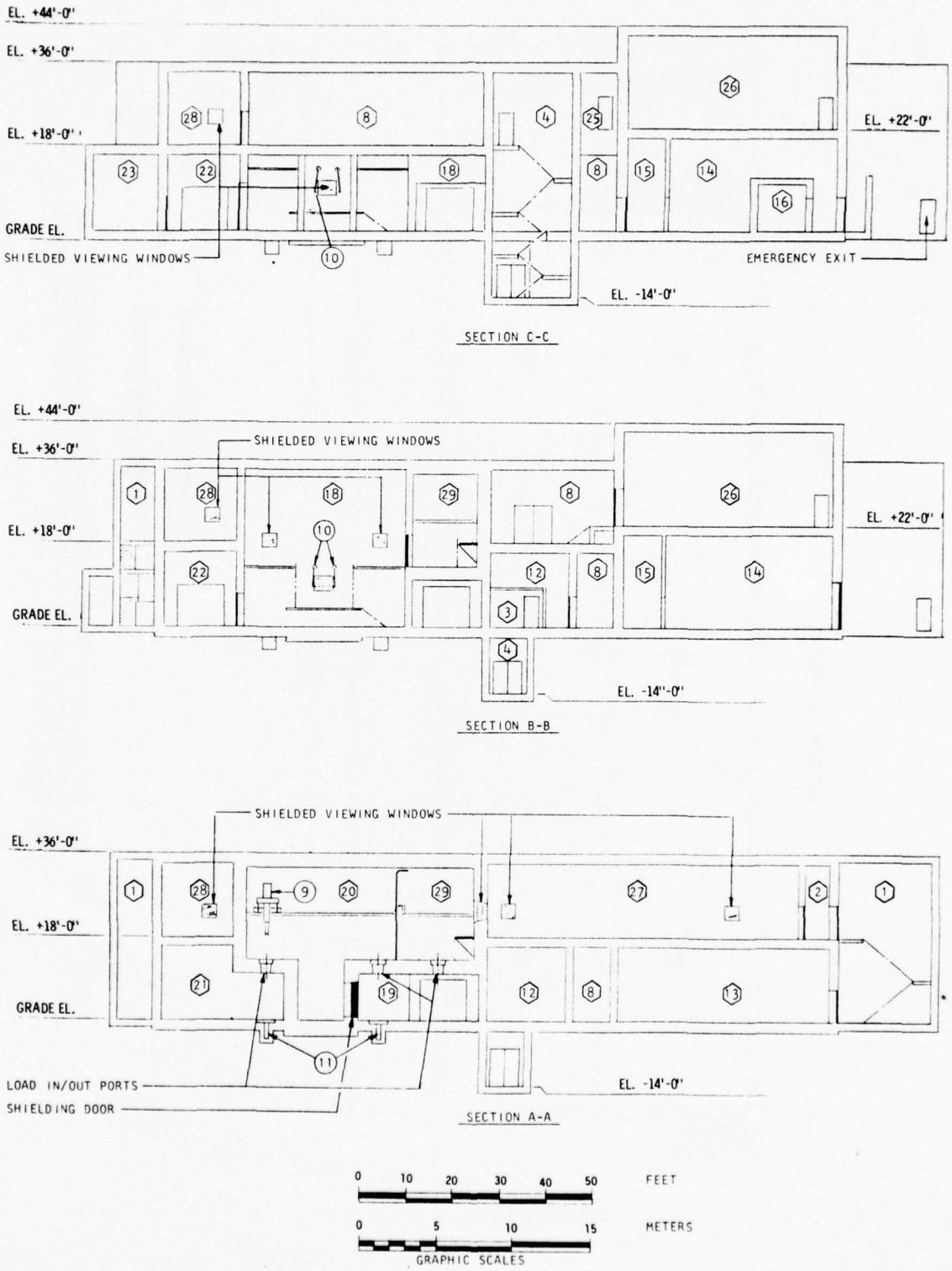
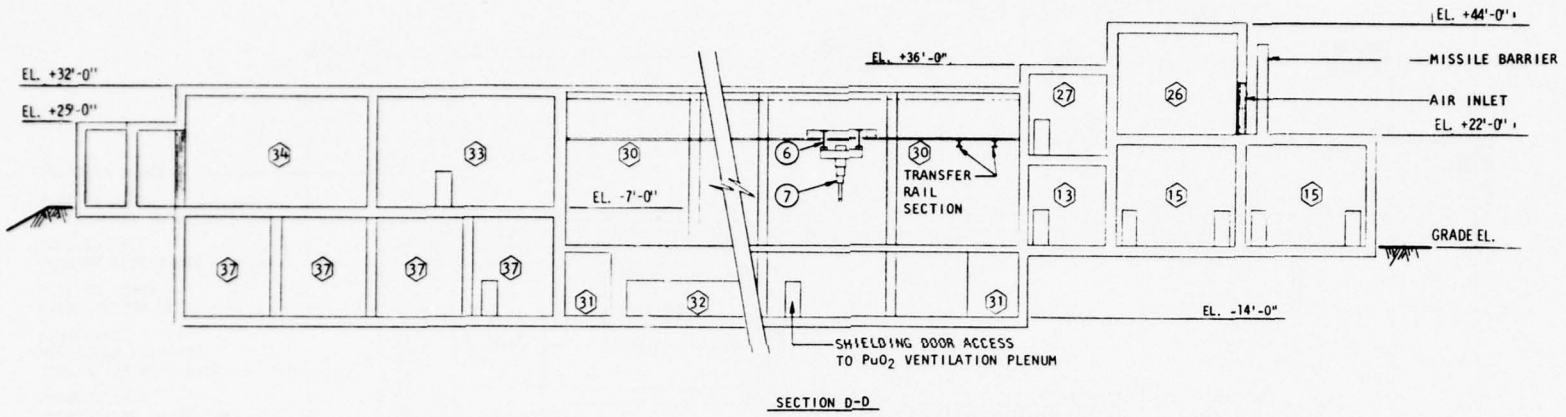


FIGURE 5.5.15. 200-MT Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant, Sections A-A, B-B, and C-C (See Figure 5.5.9 and Table 5.5.1 for number key.)



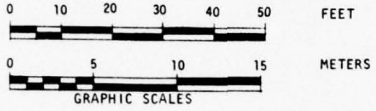


FIGURE 5.5.16. 200-MT Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant, Section D-D (See Figure 5.5.9 and Table 5.5.1 for number key.)

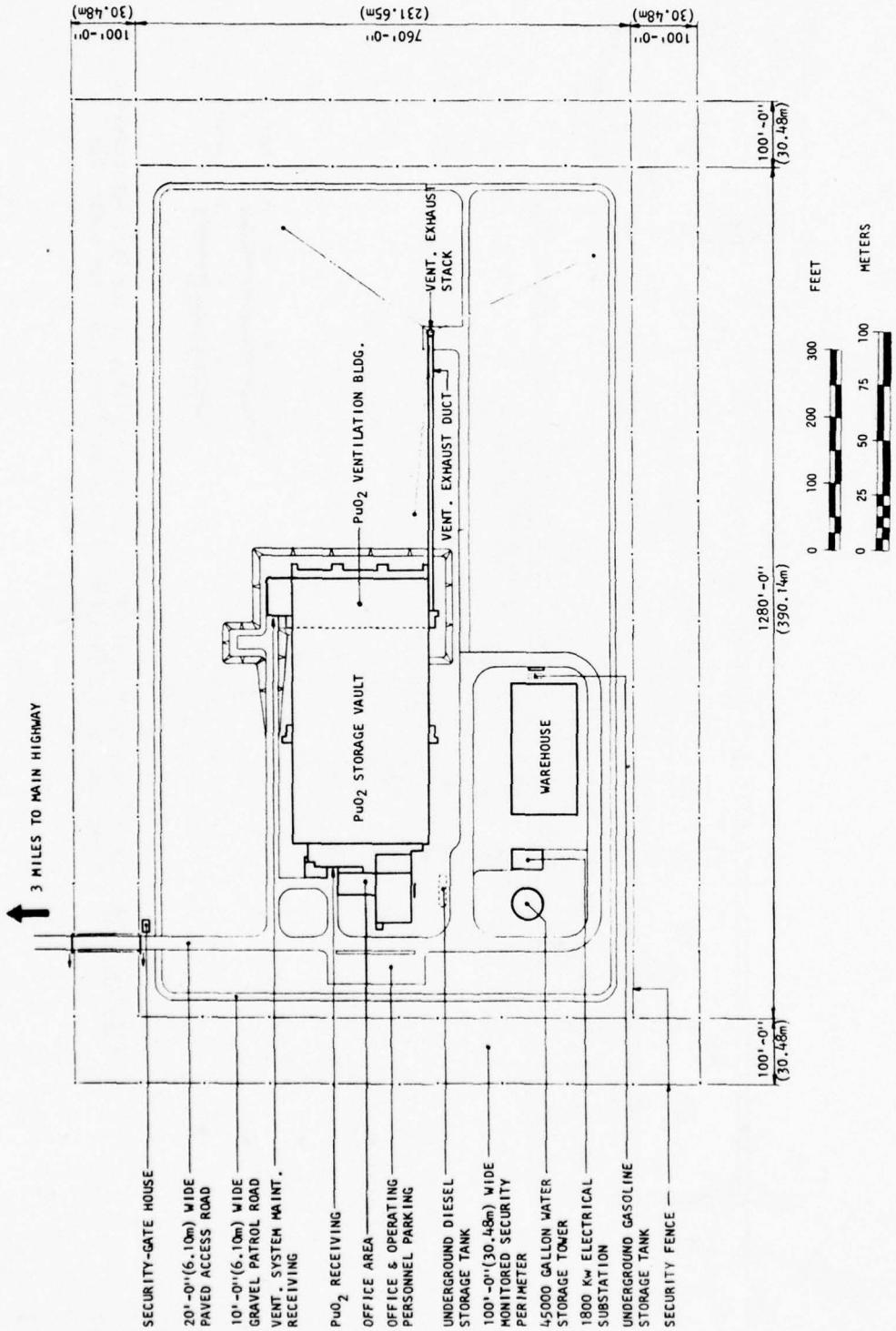


FIGURE 5.5.17. Plot Plan for the 200-MT Independent Interim Plutonium Oxide Storage Facility

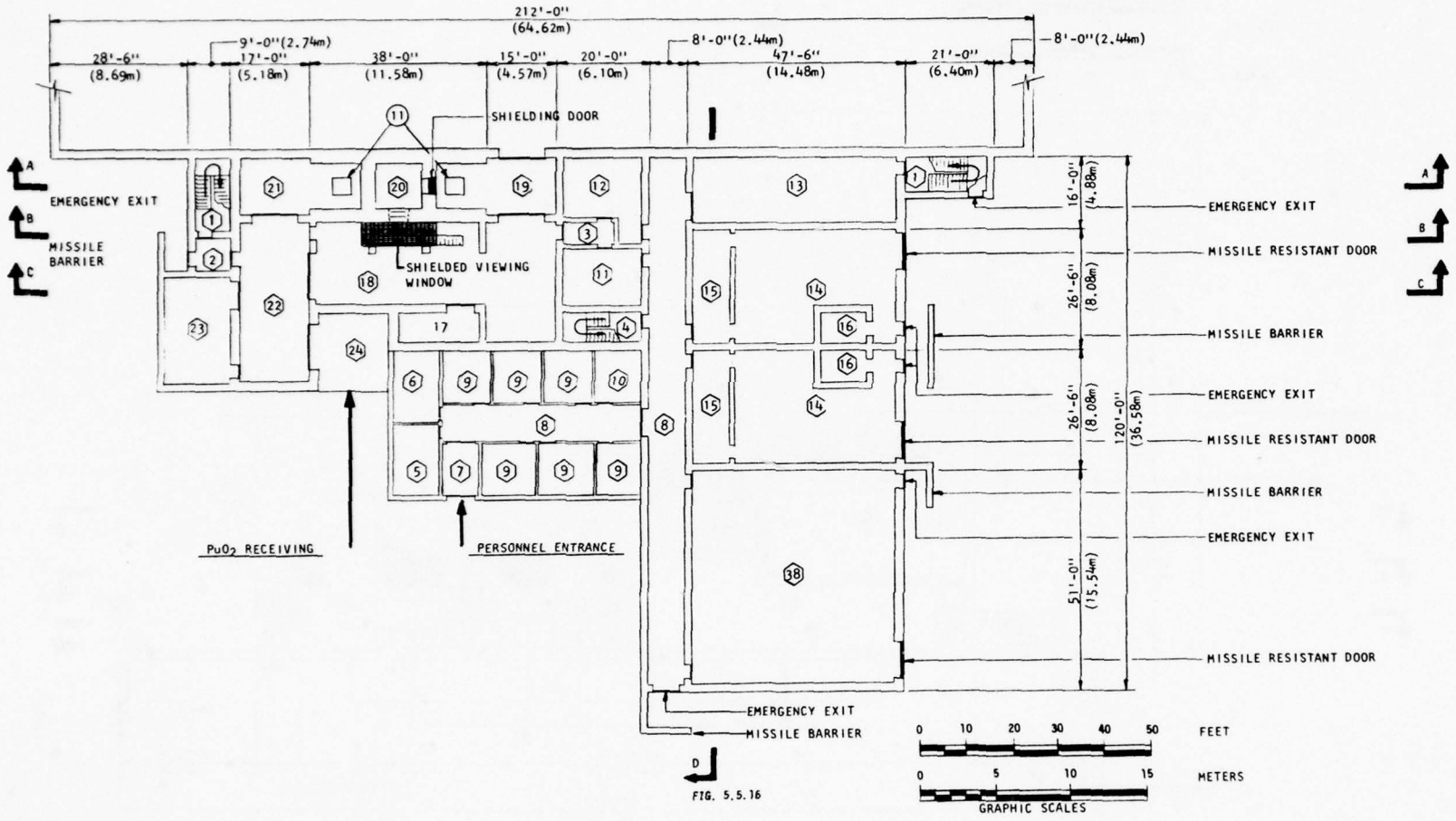


FIGURE 5.5.18. 200-MT Independent Interim Plutonium Oxide Storage Facility Plan, Plutonium Receiving Area at Grade (See Figure 5.5.9 and Table 5.5.1 for number key.)

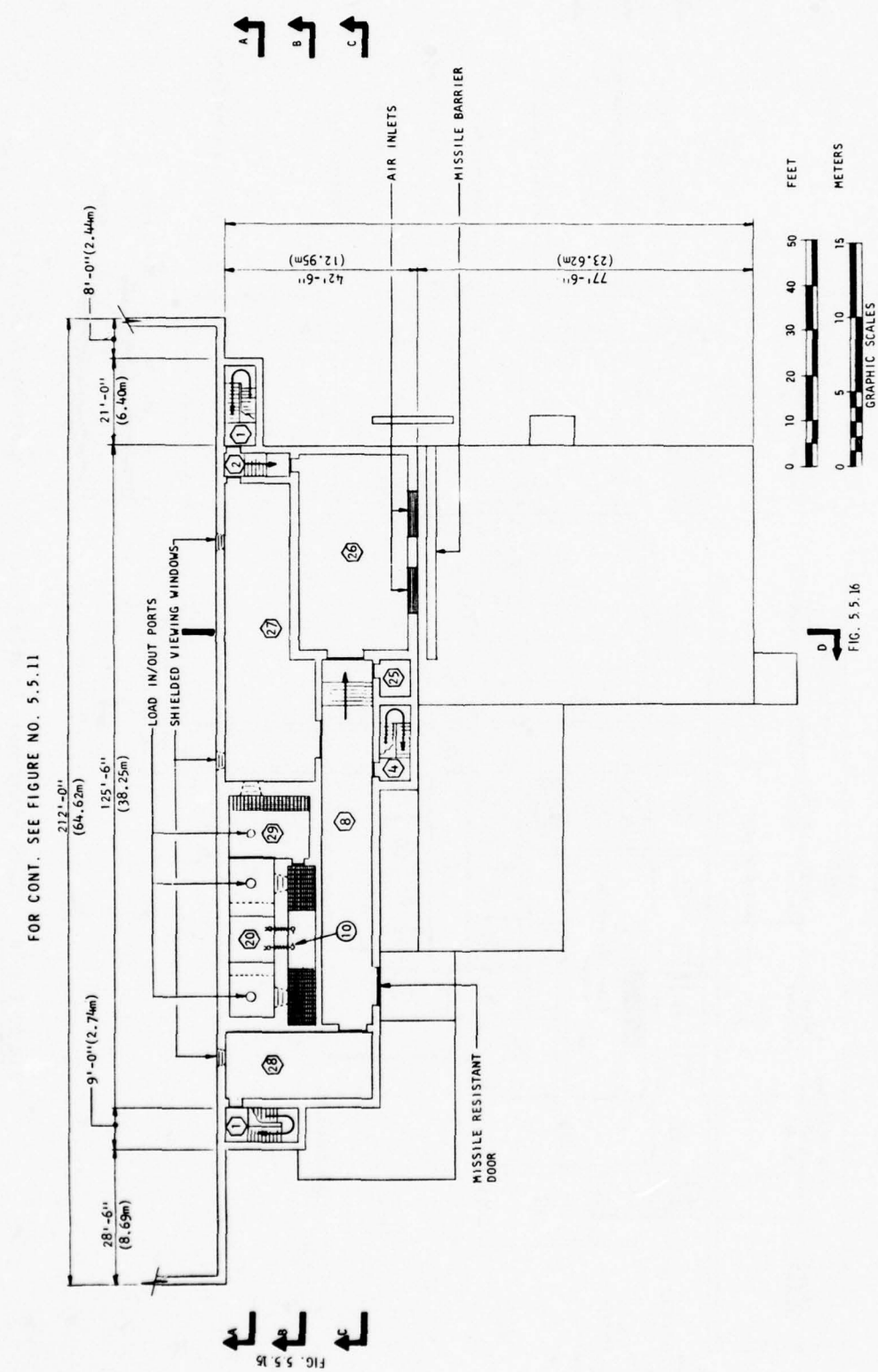


FIGURE 5.5.19. 200-MT Independent Plutonium Oxide Storage Facility Second Floor of the Plutonium Oxide Receiving Area (See Figure 5.5.9 and Table 5.5.1 for number key.)

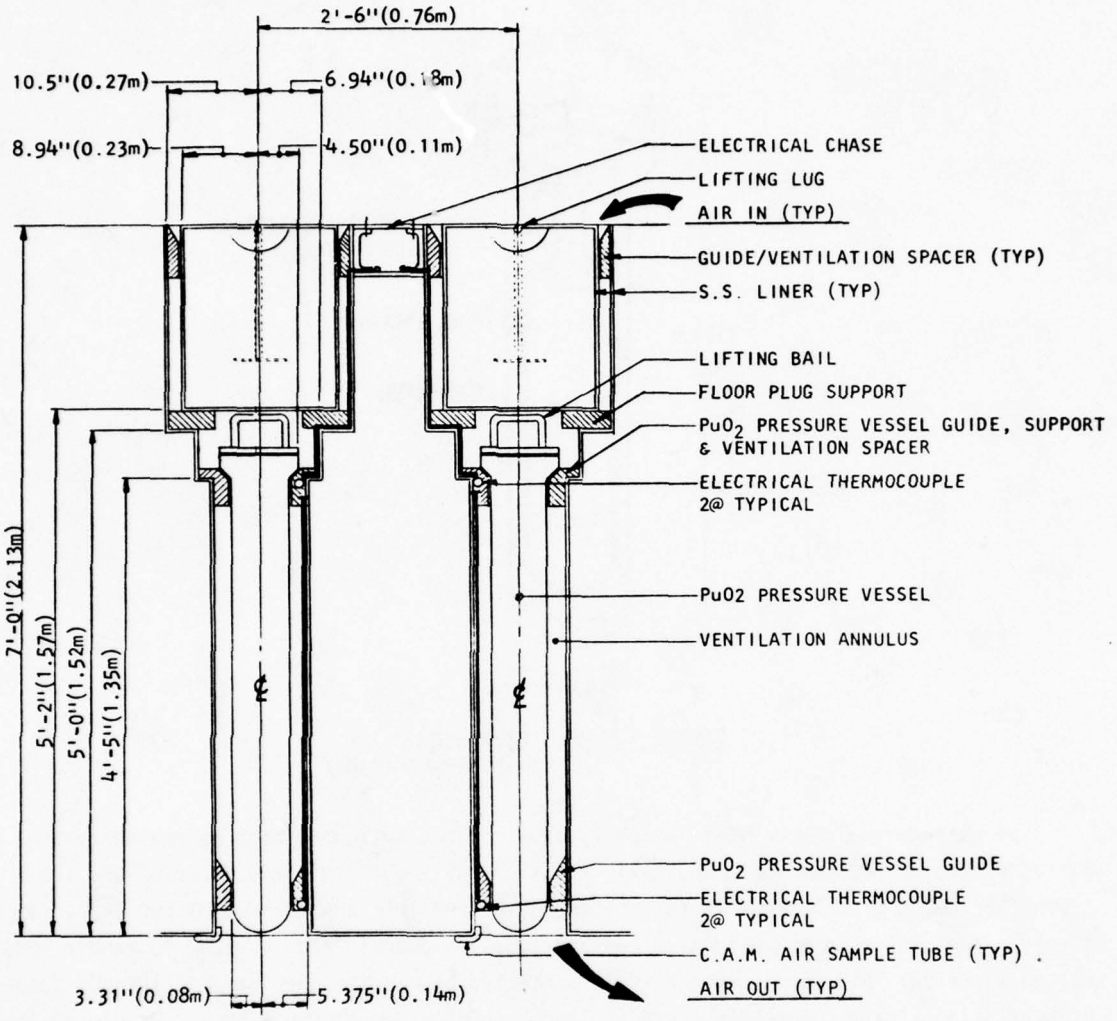


FIGURE 5.5.20. Storage Containers in Storage Slab

Ventilation System. The IPSF ventilation system is a once-through system designed to provide heating, ventilating, and air conditioning for personnel comfort and heat removal from the plutonium storage vessels. For personnel exposure and contamination control, ventilation of the storage and inspection areas is separate from that of the normally occupied control room and offices. A simplified diagram of the ventilation system is shown in Figure 5.5.22. Air flow is from the storage vault down through the annulus between the sleeve and the pressure vessel to exhaust plenums located below the storage slab. The exhaust plenums are divided by load-bearing walls that divide the air flow into separately monitored air ducts. The exhaust plenums have a floor-to-ceiling height of 1.8 m (6 ft) to allow entry for decontamination purposes.

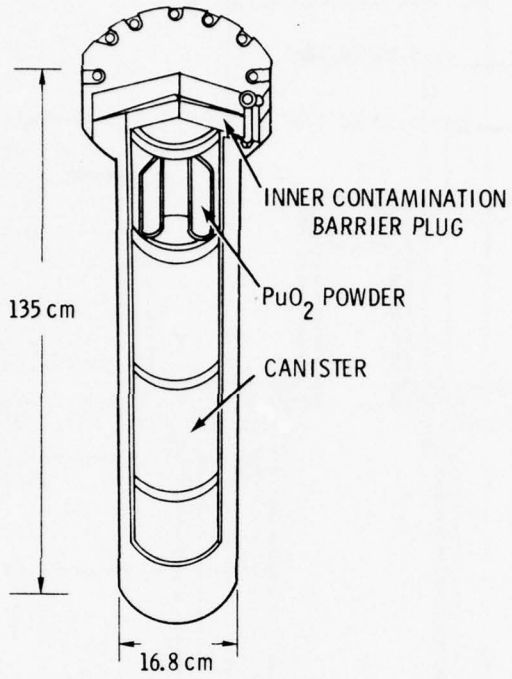


FIGURE 5.5.21. Plutonium Oxide Storage Container

The storage vault area ventilation system is sized to remove heat generated by the stored plutonium and the equipment. Air flows of 1.9×10^6 ℓ/min (68,000 cfm) and 1.0×10^7 ℓ/min (360,000 cfm) are required to cool the 30-MT FRP IPSF and the 200-MT FRP IPSF, respectively. The system is equipped with two air supply blowers; each is sized to handle 100% of design air flow. Air supply integrity is protected by missile barriers and tornado dampers. High-efficiency particulate air (HEPA) filters are provided at the exhaust outlets of the PuO_2 exhaust plenums, air locks, and exhaust plenum access aisle. The exhaust system consists of 11 final HEPA filter banks and 3 exhaust blowers for the 30-MT FRP IPSF and 60 final HEPA filters banks and 9 exhaust blowers (20 filters and 3 blowers for each of 3 vaults) for the 200-MT FRP IPSF. Each final filter bank comprises one stage of roughing filters and three stages of HEPA filters in series. Two exhaust blowers are operational, each of which handles 50% of the design air flow; the third blower is a spare.

All HEPA filters are monitored continuously for pressure drop, and provision is made for periodic survey of radioactivity and filter efficiency. Exhaust air is released through the FRP stack for the 30-MT FRP IPSF. Because of high air volume, a separate stack is provided for release of exhaust air from the 200-MT IPSFs. Normal and emergency power is available for the ventilation system.

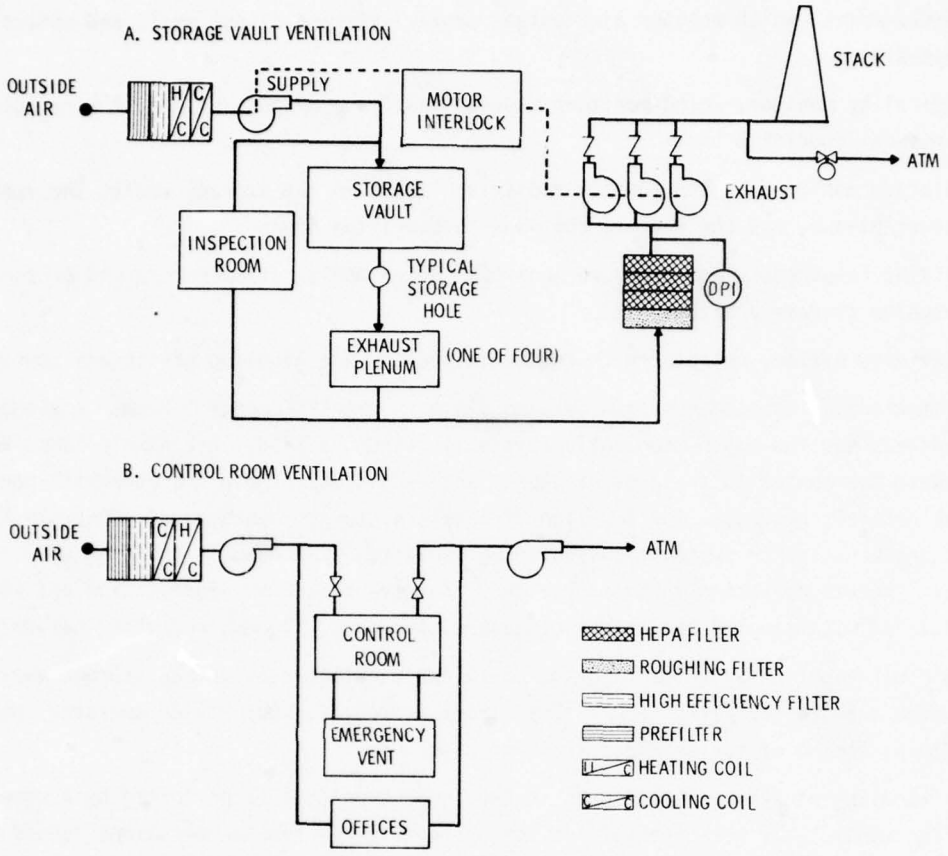


FIGURE 5.5.22. Simplified Diagram of Interim Plutonium Oxide Storage Facility Ventilation Systems

Air supplied to the inspection cell is obtained from the -51°C (-60°F) dew point dry air system. This air is supplied by the FRP for the IPSFs adjacent to the FRP. The IIPSF has its own dry air system. A prefilter and a HEPA filter are also installed at the air inlet and outlet of the inspection cell.

The control room and office area ventilation system are sized for conventional air exchange rates. A recycle ventilation system is used to isolate the control room during emergency conditions. Emergency power is available to power the recycle system.

Safety-related ventilation systems are capable of withstanding credible earthquakes, tornados, floods, and other natural phenomena.

Monitoring and Control Systems. The following safety-related instrumentation will be provided:

- continuous air monitors, which monitor coolant, storage vault, exhaust plenum, air locks, and inspection room air contamination levels

- thermocouples, which monitor air coolant supply, storage sleeve exit, and exhaust temperatures
- criticality monitor, which monitors storage vault and exhaust plenum to warn operators of a critical condition
- radiation monitors, which monitor radiation levels in the storage vault, the ventilation exhaust plenum, and the storage container preparation areas
- building temperature and pressure monitors, which monitor temperature and pressure of the plutonium storage vault
- television system, which permits remote inspection and handling of storage containers.

All monitoring instruments read out and alarm in the IPSF control room. A plant-wide public address and two-way communication system is also provided. Air sample tubes for each storage hole are routed to the exhaust plenum access aisles. These are used with portable gamma and beta air detectors for location of leaks in storage containers. Controls for the vault crane, ventilation systems, and building isolation are normally operated from the control room. Remote operation is also provided. Safety-related instrumentation and controls are capable of withstanding credible earthquakes, tornados, floods, and other natural phenomena.

Container Handling Systems. Storage container handling outside the storage vault is performed using a 5-ton fork-lift truck. This truck is modified to provide operator shielding and remote operation of the shielded transfer cask.

The handling of storage containers in the inspection cell is performed by a power manipulator. The manipulator has capabilities for performing all remote operations needed to vent, leak-test, decontaminate, open, and close the storage containers. In addition, master-slave manipulators are available to provide assistance for light-duty remote operations.

The storage vault bridge cranes are used to manipulate storage containers in the storage vault. Their operation includes transferring the shielded transfer cask unit, uncovering shield plugs, and lowering the storage container into storage holes. The cranes are pre-indexed and provided with television equipment to facilitate remote operation. They are also equipped with retractable power cable to supply power to the shielded transfer cask slide gate. Controls for the crane are normally in the control room; local controls in the storage vault are also provided. The fork-lift trucks are available for back-up and emergency operations in the storage vault. Crane capacity is 4.5 MT (5 tons).

Electrical Systems. Both normal and emergency electrical power are provided. Normal electrical power is supplied from the FRP for the adjacent IPSFs and from a separate substation for the IIPSF. Normal power requirements are about 500 kW for the 30-MT FRP IPSF and about 3300 kW for the 200-MT facilities.

Emergency electrical power is supplied by standby and back-up diesel generator sets. Fuel tanks and switch gear are provided. Emergency power requirements are about 200 kW for the 30-MT FRP IPSF and about 1500 kW for the 200-MT facilities.

Fire Protection Systems. A dry pipe sprinkler system with necessary heat (rate-of-rise) detectors and actuating devices protects the IPSF except for the inspection transfer cell and the storage vault gallery. The inspection transfer cell is protected by a chemical fire suppressant system, which provides a total flooding of 10 sec discharge with a minimum of 5% concentration and a 3-min soak time. Standpipes and firehose stations with fire extinguishers provide fire protection of all the areas of the facility including the storage vault.

Shielding and Remote Handling Equipment. Shielding is provided to ensure that radiation exposure to personnel will be maintained as low as reasonably achievable (ALARA). The dose rate levels in all operational and normally occupied areas of the IPSF are limited to 0.5 mrem/hr by shield design. Among these areas are all places where the storage containers are handled, including the storage slab floor. The storage slab shield is built as an integral part of the building. In some cases the shield is the building itself. The storage slab shield is capable of withstanding all credible accidents.

The dose rate from a newly received storage container (PPP-1 pressure vessel) is about 1 rem/hr (gamma plus neutron radiation) at the container surface. The same container after 50 years in storage would exhibit a dose rate of about 3 rem/hr (gamma plus neutron radiation) at the surface. Because of this dose rate, all movement and handling of PuO_2 containers is done in shielded casks.

Portable shields are provided to limit dose rates while the containers are being transferred within the facility; the shielding meets the design dose rate limit of 0.5 mrem/hr. The designs and materials of these shields are shown in Figure 5.5.23. The PPP-1 shipping container overpack is used for shielding during shipment and while moving the shipping container from the truck to the inspection and transfer cell. No shields are provided for container handling in the inspection and transfer cell since the operations there are done remotely. A shielded transfer cask is used for shielding while moving the shipping container between the inspection and transfer cell and the storage array. Special remote control capabilities are provided on the vault crane and the fork-lift trucks to open and close the transfer cask sliding door.

5.5.1.5 Operating and Maintenance Requirements for the Interim Plutonium Oxide Storage Facility

Operation of the IPSF is continuous while plutonium is in storage. Storage container receipt, transfer, and maintenance may be limited to one or two shifts per day. Continuous surveillance of stored containers is required.

Supplies and Utilities. The IPSFs require cleaning chemicals and materials for decontaminating storage containers and areas where the containers are handled. Other supplies common to the operating of a large warehouse are also required.

Table 5.5.3 gives estimates of the annual utility requirements for operating the IPSFs.

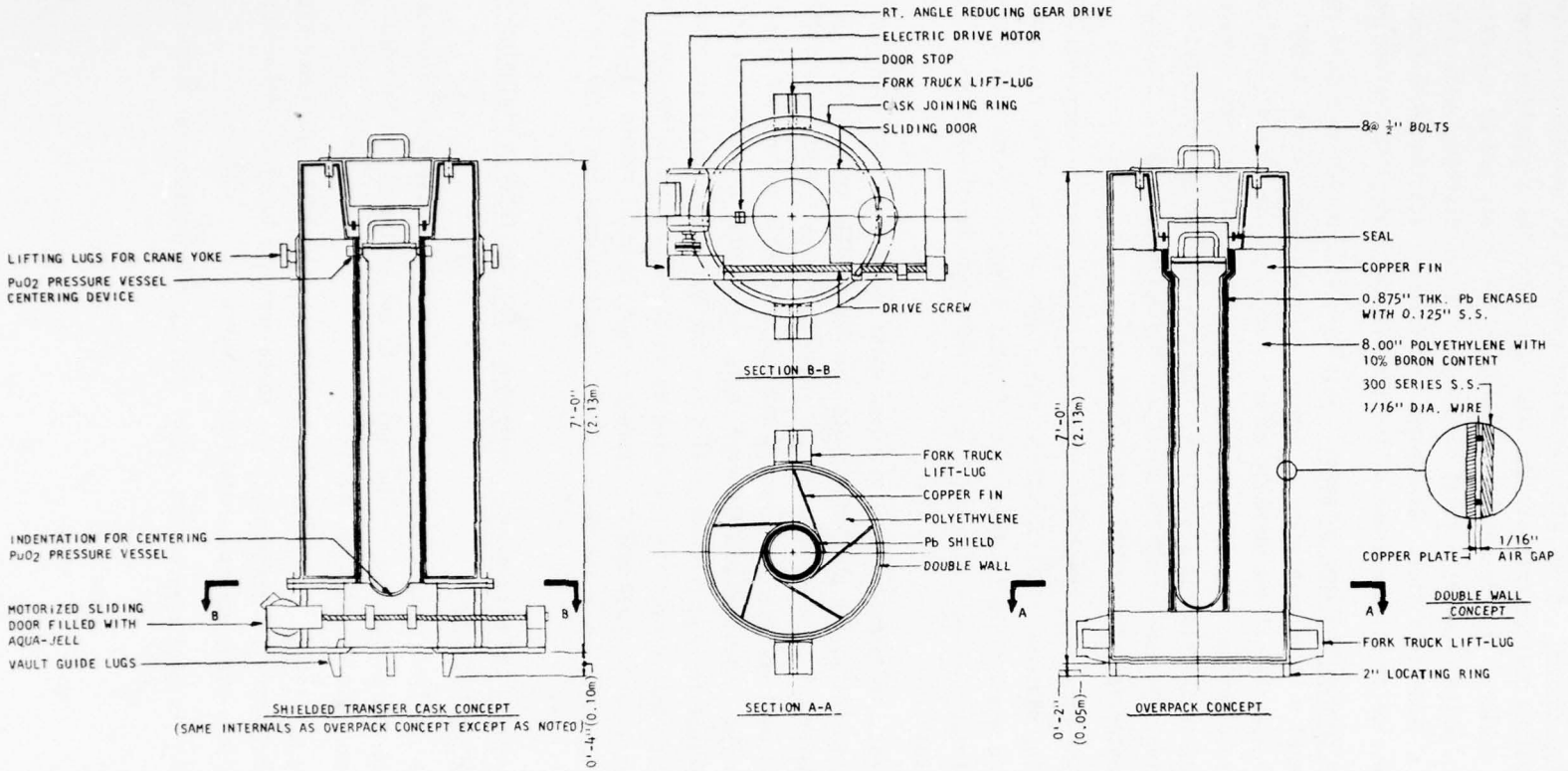


FIGURE 5.5.23. Portable Shields

TABLE 5.5.3. Interim Plutonium Oxide Storage Facility Utility Requirements

	30-MT FRP IPSF		200-MT FRP IPSF		200-MT IIPSF	
	Use Rate	Annual Requirement	Use Rate	Annual Requirement	Use Rate	Annual Requirement
Electricity	525 kW	4.6×10^6 kWh	3200 kW	2.8×10^7 kWh	3300 kW	2.9×10^7 kWh
Water consumed	3000 kg/hr	2.7×10^7 kg	18000 kg/hr	1.6×10^8 kg	18000 kg/hr	1.6×10^8 kg
Steam	230 kg/hr	2.0×10^6 kg	1370 kg/hr	1.2×10^7 kg	1370 kg/hr	1.2×10^7 kg
Oil	0.2 m^3/hr	10 m^3	2 m^3/hr	100 m^3	2 m^3/hr	100 m^3

Staffing Requirements. Staffing requirements for the three IPSFs are shown in Table 5.5.4. Three operating shifts are required, 7 days per week. Additional manpower for operation of the 30-MT FRP IPSF and the 200-MT FRP IPSF may be obtained, as needed, from the nearby FRP.

Fifteen guards are assigned to the IPSF. This number is consistent with current NRC requirements for nuclear power plants.

TABLE 5.5.4. Interim Plutonium Oxide Storage Facility Staffing Requirements

	Personnel Required, Man-yr/yr		
Job Description	30-MT FRP IPSF	200-MT FRP IPSF	200-MT IIPSF
Operators	12	12	17
Radiation monitors	8	8	12
Maintenance craftsmen	12	12	17
Guards	15	15	15

Hazardous Material. The main hazardous material at each of the three IPSFs is plutonium oxide. In addition, diesel fuel will be stored at each facility for operation of the emergency diesel generators.

5.5.1.6 Secondary Wastes for the Interim Plutonium Oxide Storage Facility

Secondary radioactive wastes associated with the 30-MT IPSF are shown in Table 5.5.5. Secondary wastes associated with the 200-MT facility are approximately six times larger.

TABLE 5.5.5. 30-MT Interim Plutonium Oxide Storage Facility Secondary Wastes

Description	Volume, m^3/yr	Radioactivity Factor[a]
Combustible and compactable waste	13	3×10^{-7}
Failed equipment	negligible	negligible
Wet wastes	negligible	negligible

a. Fraction of inventory activity (Table 5.5.1) per year in secondary wastes.

5.5.1.7 Facility Emissions from the Interim Plutonium Oxide Storage

Estimated facility emissions for the 30-MT IPSF is characterized in Table 5.5.6. Non-radiological emissions for the 200-MT facilities are approximately six times larger.

TABLE 5.5.6. Emissions from the 30-MT Interim Plutonium Oxide Storage Facility

Emission	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere(a)
Gaseous	Building ventilation air	1.0×10^{9} m^3	4×10^{-17}
	Minor accident integrated annual release		None Identified
Cooling tower water	Evaporated T = 38°C	1.4×10^{7} kg	
	Drift T = 38°C	7.0×10^{4} kg	
	Blowdown T = 27°C	2.5×10^{6} kg	
Other	Heat	9.4×10^{3} MW-hr (3.3×10^{10} BTU)	

a. Fraction of inventory activity (Table 5.5.1) released per year. Release is uniform over year.

5.5.1.8 Interim Plutonium Oxide Storage Facility Decommissioning Considerations

Useful life of the IPSF could be 50 years or more. Actual life will depend on the ultimate disposition of the plutonium product. Residual radioactivity could result from plutonium product escape from a leaking storage container or residual surface contamination on the storage containers. Any residual radioactivity should be confined to the inspection and transfer cell, the storage sleeves, the ventilator exhaust plenums, and the ventilation exhaust system (primarily the HEPA filters).

5.5.1.9 Postulated Accidents for the Interim Plutonium Oxide Storage Facility

Safe storage of PuO_2 in PPP-1 pressure vessels requires criticality-safe spacing of the storage containers during handling and storage; maintenance of cooling for the storage containers; and maintenance of the structural integrity of the storage slab, cooling equipment, and containment during all postulated accident conditions. The staff at the IPSF will be technically skilled in the operation of all safety and handling equipment. They will be trained to handle all types of emergencies.

Since the PPP-1 container design has not been used, no data from actual experience are available on its operational performance. Scenarios describing loss of normal electrical power, loss of ventilation blower, and trash fire are possible for any industrial facility involving similar equipment and operations. Other types of accidents involving storage container damage or failure are hypothetical.

Postulated credible accident scenarios for the IPSF are given in Tables 5.5.7 through 5.5.9 for minor, moderate, and severe accidents. Table 5.5.10 gives radioactive source terms related to the postulated criticality accident (Accident 5.5.6).

For purposes of environmental consequence analysis, the material release associated with accidents numbered 5.5.4, 5.5.5 and 5.5.6 in Tables 5.5.8 and 5.5.9 have been selected as umbrella source terms. (The concept of an umbrella source term is explained in Section 3.7 - Basis for Accident Analysis.) This means that the releases from these accidents are the largest in their respective source term categories. Accidents are cross indexed with their appropriate umbrella source term in Appendix A, Section 3. The environmental consequences of these accidents are described in DOE/ET/0029.

TABLE 5.5.7. Interim Plutonium Oxide Storage Facility Minor Accidents

Accident No. and Description	Sequence of Events	Safety System	Release
5.5.1 - Loss of normal electrical power, expected frequency, ~1 per year.	1. Power to substation supplying the IPSF interrupted. 2. Electrical equipment stops. 3. Emergency power supplied to the facility. Limited equipment operation. 4. Normal power restored; operations resume.	1. Emergency power diesel generators (several redundant emergency power supplies).	none
5.5.2 - Temporary loss of ventilation blower; expected frequency, ~0.5 per year.	1. Ventilation blower in PuO_2 cooling system fails. 2. Spare ventilation blower started. 3. Normal operations resume; blower repaired.	1. Spare ventilation blowers.	none

TABLE 5.5.8. Interim Plutonium Oxide Storage Facility Moderate Accidents

Accident No. and Description	Sequence of Events	Safety System	Release
5.5.3 - Decontamination trash fire, expected frequency, ∿0.5 per year.	1. Storage container decontamination materials ignite. 2. Contaminated smoke enters ventilation system. 3. Contamination leaves stack after passing through HEPA filters. 4. Fire put out; facility decontaminated; filters replaced. 5. Operations resumed.	1. Smoke detectors. 2. Automatic and manual fire-fighting equipment. 3. Activity released from burning materials removed by HEPA filters.	$\sim 10^{-13}$ g of PuO_2 from plant stack.
5.5.4 - Storage container leakage; expected frequency, ∿0.1 per 1000 stored containers per year.	1. Storage container develops leak. 2. Contamination (PuO_2) enters ventilation system. 3. Contamination leaves stack after passing through HEPA filters. 4. Leaking storage container located and repaired. 5. Facility decontaminated. 6. Operations resume.	1. Storage container maintenance in combination with low seal stress will minimize occurrence of this event. 2. Ventilation system is monitored for plutonium contamination and can be isolated. 3. Activity released is removed by HEPA filters.	$\sim 10^{-10}$ g of PuO_2 from plant stack.

Criticality. The reference facility is designed to ensure that an accidental chain reaction is not credible. Each storage canister is limited to a quantity of PuO_2 that is adequately subcritical. Once the quality and quantity of PuO_2 in each canister has been established, the canister is closed and sealed at the reprocessing plant. The canisters are also loaded and sealed into the pressure vessel at the reprocessing plant.

Pressure vessels are moved about the IPSF in either the transportation overpack or the shielded transfer cask (except in the inspection and transfer cell). This procedure maintains adequate subcriticality even if the casks are in close proximity. The limited number of transfer casks and overpacks prevents having a large number of vessels in transport at one time. Administrative procedures also limit the number of pressure vessels in transport out of the storage sleeve. At no time will the canisters from any pressure vessel be unloaded in the facility.

TABLE 5.5.9. Interim Plutonium Oxide Storage Facility Severe Accidents

Accident No. and Description	Sequence of Events	Safety System	Release
5.5.5 — Storage container breach; estimated frequency, $\sim 1 \times 10^{-6}$ per handling operation.	1. Plutonium storage container punctured. 2. Plutonium product spilled. 3. Plutonium product becomes airborne and enters ventilation system. 4. Contamination leaves stack after passing through HEPA filters. 5. Ventilation system isolated; storage container placed in overpack. 6. Ventilation system restarted; plant decontaminated. 7. Operations resumed.	1. Activity released from spilled plutonium product is removed by HEPA filters. 2. Procedures will require extreme care during handling of containers. 3. Container is designed for transportation accidents. 4. Administrative controls and interlocks will reduce likelihood of this accident.	$\sim 2 \times 10^{-8}$ g of PuO_2 from plant stack.
5.5.6 — Plutonium product criticality, estimated frequency less than 2×10^{-5} per year.	1. Plutonium product collects in favorable geometry outside of storage containers. 2. Nuclear criticality occurs. 3. Plutonium product and fission products enter ventilation system. 4. Contamination leaves stack after passing through HEPA filters. 5. Facility isolated. 6. Critical mass disassembles or "burns out". 7. Source of plutonium identified; leak repaired; facility decontaminated. 8. Operations resume.	1. Contamination monitors to detect leakage from storage containers. 2. Administrative controls prevent criticality in material stored in a container. 3. Radiation and criticality monitors give rapid warning of events to initiate operator evacuation and plant isolation. 4. Criticality is self-controlling since sufficient energy is released to separate and disperse powdered mass. 5. Activity release is reduced by HEPA filters.	$\sim 2 \times 10^{-8}$ g of PuO_2 plus fission produced sources listed in Table 5.5.10 from plant stack.

TABLE 5.5.10. Radioactive Source Terms for Postulated Criticality Event (10^{19} Fissions)

Nuclide	Release in 0 to 0.5 hr, Ci	Release in 0.5 to 8 hr, Ci	Total Release, Ci
^{83m}Kr	3.7×10^{0}	3.3×10^{1}	3.7×10^{1}
^{85m}Kr	1.6×10^{1}	1.5×10^{2}	1.7×10^{2}
^{85}Kr	1.5×10^{-4}	1.4×10^{-3}	1.6×10^{-3}
^{87}Kr	1.0×10^{2}	9.0×10^{2}	1.0×10^{3}
^{88}Kr	6.5×10^{1}	5.9×10^{2}	6.6×10^{2}
^{89}Kr	4.1×10^{3}	3.7×10^{4}	4.1×10^{4}
^{131m}Xe	3.8×10^{-4}	3.5×10^{-3}	3.9×10^{-3}
^{133m}Xe	5.5×10^{-2}	4.9×10^{-1}	5.5×10^{-1}
^{133}Xe	1.3×10^{0}	1.2×10^{1}	1.3×10^{1}
^{135m}Xe	1.1×10^{1}	9.9×10^{1}	1.1×10^{2}
^{135}Xe	1.6×10^{1}	1.5×10^{2}	1.7×10^{2}
^{137}Xe	3.8×10^{3}	3.5×10^{4}	3.9×10^{4}
^{138}Xe	1.2×10^{3}	1.0×10^{4}	1.1×10^{4}
^{129}I	4.2×10^{-11}	3.9×10^{-10}	4.3×10^{-10}
^{131}I	1.8×10^{-1}	1.6×10^{0}	1.8×10^{0}
^{132}I	6.7×10^{-1}	6.1×10^{0}	6.7×10^{0}
^{133}I	3.5×10^{0}	3.1×10^{1}	3.5×10^{1}
^{134}I	4.8×10^{1}	4.3×10^{2}	4.8×10^{2}
^{135}I	1.2×10^{1}	1.0×10^{2}	1.2×10^{2}

Note: Table taken from Reference 5.

Essential assumptions regarding the PuO_2 are that it initially meets dry powder specifications and that the powder remains dry. For criticality safety assessments the plutonium composition is assumed to be as follows:

Isotopic composition -95 wt% ^{239}Pu, 5 wt% ^{240}Pu (minimum)
Powder density -3.5 g PuO_2/cm^3 (maximum)
Moisture content -1 wt% H_2O (maximum)

To ensure conservatism in criticality calculations, the geometry of the storage containers has been assumed such that the plutonium product loading is 71 kg (157 lb) per container. This loading is based on the assumption that PuO_2 fills the entire container volume except for a cylinder void 5 cm (2 in.) in diameter.

Subcriticality of the Storage Canister in the Storage Array. An individual storage container will be subcritical based on the container geometry and mass limitation. The storage array loaded with PuO_2 as described in the previous section will be subcritical based on the use of concrete between storage holes to limit neutron interaction. Under the conditions given in this report involving PuO_2 loading and array geometry, an infinite array of storage containers is adequately subcritical both dry and flooded with water. Results of these calculations are presented in Table 5.5.11.

Subcriticality of Storage Containers Outside of Shipping Overpacks, Shielded Transfer casks, and Storage Array. To preclude a criticality potential from loose containers, administrative controls will be imposed. The number and proximity of containers inside or outside the shipping overpacks and shielded transfer will be limited. Calculations assessing criticality potential have been performed assuming violation of the administrative controls. Descriptions of the calculations and results are also shown in Table 5.5.11. The margin of safety and number or errors before a criticality potential could exist can be estimated from these calculations.

TABLE 5.5.11. Results of Criticality Calculations as Affected by the Storage Array and Potential Administrative Control Violations

Configuration	Description	k_{eff} (a,b)
Dry infinite storage array	A dry infinite size storage array having as-designed dimensions	0.666 ± 0.004
Water flooded infinite array	An infinite size storage array having as-designed dimension, but with water in all accessible air spaces	0.724 ± 0.004
Two loaded containers in contact	PuO_2-bearing portion of two storage containers in contact; concrete reflection on two sides (long axis)	0.790 ± 0.008
2 x 2 array of loaded containers	2 x 2 array of containers in a corner of the facility to give concrete reflection on two sides and bottom of the array; air space on other two sides; steel on top; container spacing assumed to be 30.48 cm (12 in.) center-to-center	0.695 ± 0.006
4 x 4 array of loaded containers	Same as above except 4 x 4 array	1.010 ± 0.006
Dropped container	Container is dropped in corner of facility; three-wall concrete reflection; air space on other two sides; steel on top; all PuO_2 powder falls to bottom of container	0.520 ± 0.005

a. Calculations were made using ENDF/B-IV 18-group cross sections and KENO-IV criticality program (see Reference 6).
b. k_{eff} <1.0 implies subcritical; k_{eff} = 1.0 implies critical; k_{eff} >1.0 implies supercritical.

Design Basis Criticality Accident. The criticality accident postulated in Table 5.5.9 encompasses three potential instances of criticality within the IPSF:

1. Criticality of the Storage Container in the Storage Slab
   On the basis of the infinite array criticality analytical results presented in Table 5.5.11, criticality of a storage container in the storage slab is not credible.

2. Criticality of the Storage Container Outside the Storage Array
   Calculation results presented in Table 5.5.11 indicate that mishandling of the storage containers outside the storage slab, the shielded transfer cask, and the transport overpack could lead to a criticality accident. However, administrative controls will limit the number and separation of storage containers that may be present at one time in all areas where containers are handled. The calculations indicate that five or more containers would have to be placed in close proximity to cause a criticality accident. This would require at least four separate violations of administrative procedures. For this reason a criticality accident occurring in the storage containers outside the storage array is not credible.

3. Criticality of PuO_2 Powder Outside the Storage Containers
   The minimum critical mass for dry PuO_2 at a density of 3.0 g of plutonium per cubic centimeter with full water reflection is 65 kg (144 lb) of plutonium. The minimum critical mass for fully moist PuO_2 with the same density and reflection conditions is 12 kg (26 lb) of plutonium.[7] Thus, it could be postulated that if a container were damaged (e.g., in handling) and PuO_2 were spilled, nuclear criticality could occur. This criticality event is highly unlikely, however, since it would require successive occurrences of several low probability events.

   The energy released in this accident would probably upset the critical configuration and reduce it to a subcritical state. It is assumed that a single burst of 10^{19} fissions would disrupt the critical configuration of powder. Additional assumptions for this criticality event include:

   - release time of 8 hours
   - release via facility filters
   - 100% of noble gases released to the atmosphere
   - 25% of iodine released to the atmosphere
   - 200 g of stored plutonium oxide is released to the filters
   - release inventory for fission products as shown above in Table 5.5.8.

   No physical damage to the facility or equipment would result from such an accident. Building personnel might be exposed to neutron and gamma radiation in varying degrees of severity and possibly to plutonium contamination. Contamination of some portions of the building would probably also occur.

Plutonium Self-Heating and Confinement. Plutonium oxide in storage containers is a source of heat that must be dissipated to ensure confinement of the plutonium. During normal conditions the IPSF will have a heat-removal system that will be a part of the building

ventilation system. This ventilation system is connected to the emergency electrical supply system to prevent loss of air coolant owing to loss of normal electrical power. Reduced but adequate air flow will be maintained. The storage slab and essential ventilation equipment are designed to withstand design basis tornados and earthquakes. For these reasons a total and sustained loss of air coolant is not considered a credible event.

The PPP-1 pressure vessel will provide the principal plutonium confinement barrier. This container is designed to ensure plutonium product confinement during postulated accident conditions encountered in transportation. The design necessary to meet transportation requirements will also ensure plutonium confinement during the less severe accident conditions postulated during IPSF operation. The IPSF building will be the final containment structure.

Container Pressurization. Pressurization of the storage container as a result of the residual moisture in the plutonium product and alpha decay of plutonium and daughter products is recognized as a potential hazard. Radiolysis of water in the container produces hydrogen and oxygen; alpha decay produces helium gas. The IPSF inspection and transfer cell is equipped to safely vent the pressure vessels as required. The final design of the PPP-1 container is expected to preclude the possible combustion or explosion of hazardous gas mixtures by removing the gases as they are formed or by containing the gases under all possible conditions.

5.5.1.10 Costs for the Interim Plutonium Oxide Storage Facility

Estimates have been made in mid-1976 dollars of capital, operating, and levelized unit costs. A complete description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Costs. The capital cost estimates for the 30-MT FRP IPSF and the 200-MT FRP IPSF are shown in Tables 5.5.12 and 5.5.13, respectively. The estimates cover all capital costs specifically resulting from inclusion of the IPSF as an added operational facility of the FRP described in Section 3.2.3. The capital costs also include PuO_2 casks involved in the handling of plutonium during storage operations. However, no allocation of general FRP costs for such services as laboratories, warehousing, compressed or dry air supply, and effluent stack is made to the IPSF capital cost.

The capital cost estimate for the 200-MT IPSF is shown in Table 5.5.14. The estimate is representative of a first-generation PuO_2 storage plant built at a midwestern site and licensed for operation in the 1980-1990 period. The estimate also reflects anticipated costs associated with stringent health physics, safety measures, and safeguards and security programs.

The total capital cost for all IPSFs includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation with the exception of working capital and the costs of shipping casks and the PuO_2 canisters and pressure vessels. These costs are included in Transportation costs, in Section 6.5.1.6.

TABLE 5.5.12. Capital Cost Estimate for the 30-MT FRP Interim Plutonium Oxide Storage Facility

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		60	2,200	700	2,900
Building and structures		500	6,200	5,900	12,100
Bulk materials		100	3,500	1,200	4,700
Site improvements		—	—	—	—
Subtotal of direct site construction costs		660	11,900	7,800	19,700
Indirect site construction costs	140	140	2,800	3,800	6,600
Total field cost	140	800	14,700	11,600	26,300
Architect-engineer services					4,700
Subtotal					31,000
Owner's cost					9,000
Total facility cost					40,000
Estimate accuracy range					±20%

TABLE 5.5.13. Capital Cost Estimate for the 200-MT FRP Interim Plutonium Oxide Storage Facility

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		270	3,400	3,200	6,600
Buildings and structures		2,800	34,300	33,600	67,900
Bulk materials		570	18,700	6,800	25,500
Site improvements		—	—	—	—
Subtotal of direct site construction costs		3,640	56,400	43,600	100,000
Indirect site construction costs	800	730	16,000	21,100	37,100
Total field cost	800	4,370	72,400	64,700	137,100
Architect-engineer services					24,900
Subtotal					162,000
Owner's cost					49,000
Total facility cost					211,000
Estimate accuracy range					±20%

TABLE 5.5.14. Capital Cost Estimate for the 200-MT Independent Interim Plutonium Oxide Storage Facility

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		280	4,400	3,300	7,700
Buildings and structures		2,820	34,700	33,800	68,500
Bulk materials		670	20,100	8,000	28,100
Site improvements		80	1,700	1,000	2,700
Subtotal of direct site construction costs		3,850	60,900	46,100	107,000
Indirect site construction costs	850	770	16,900	22,300	39,200
Total field cost	850	4,620	77,800	68,400	146,200
Architect-engineer services					26,600
Subtotal					172,800
Owner's cost					52,200
Total facility cost					225,000
Estimate accuracy range					±20%

The accuracy range reflects uncertainties in the engineering scope required to provide a fully functional facility based on the technology described and in the pricing and quantities for labor, materials, and equipment. A contingency covering these and similar factors has been included in the base estimates. With the contingency included, there is an approximately equal likelihood of the indicated cost overrun or underrun.

Table 5.5.15 shows the capital expenditure schedule if 30-MT facilities are used for 10-year storage of the PuO_2 from a 2000 MT/yr FRP. The annual loading rate is approximately 18 MT PuO_2 per year. The schedule shows that six facilities would be required. The last 30-MT facility coming on line in year 10 would only have 2 MT PuO_2 stored at the end of that year.

Table 5.5.16 illustrates the capital expenditure schedule for the above scenario using 200-MT PuO_2 storage facilities. Only one facility would be required and would be about 85% loaded in 10 years.

Table 5.5.17 gives the capital expenditure schedule for a centrally-located, Federally-owned 200-MT IPSF at our independent site. This facility would receive fuel from several reprocessing plants and store it until the year 2000. The maximum receiving rate would be approximately 64 MT PuO_2 annually. Four facilities would be required based on material flows from a nuclear power generation scenario of 400 GWe in the year 2000. The last facility would only be about one-third full.

TABLE 5.5.15. Operating Scenario for 10-Year Storage at the 30-MT Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant

Year	Cumulative PuO_2 Stored, MT	Cumulative Equivalent, MTHM	Capital Expenditure To Construct New Plant, $ in Millions
0			40
1	6	667	
2	18	2,000	40
3	36	4,000	
4	54	6,000	40
5	72	8,000	
6	90	10,000	40
7	108	12,000	
8	126	14,000	40
9	144	16,000	40
10	162	18,000	

TABLE 5.5.16. Operating Scenario for 10-Year Storage at the 200-MT Interim Plutonium Oxide Storage Facility at the Fuel Reprocessing Plant

Year	Cumulative PuO_2 Stored, MT	Cumulative Equivalent, MTHM	Capital Expenditure $ in Millions
0			211
1	6	667	
2	18	2,000	
3	36	4,000	
4	54	6,000	
5	72	8,000	
6	90	10,000	
7	108	12,000	
8	126	14,000	
9	144	16,000	
10	162	18,000	

Operating Costs. Operating costs are shown in Table 5.5.18 for the three types of plutonium oxide storage facilities under consideration. Estimates of direct labor were made using the manpower data in Table 5.5.4. Guards were included in the direct labor because of the special security requirements. Process materials consist of the PuO_2 containers and primary pressure vessels, at an approximate cost of $2500 per set (four containers and one pressure vessel). Utilities costs are based on requirements given in Table 5.5.2. Annual maintenance materials costs are estimated at 2% of the initial equipment cost. Estimates for miscellaneous costs are assumed to include all unidentified operating costs. The costs of taxes, insurance, and interest, however, are included in the capital segment of the levelized unit cost.

TABLE 5.5.17. Operating Scenarios for Storage to Year 2000 at the 200-MT Independent Interim Plutonium Oxide Storage Facility

Year	Cumulative PuO_2 Stored MT	Cumulative Equivalent, MTHM Processed	Capital Expenditure for New Plants $ in Millions
1980			225
1981	4	500	
1982	12	1,500	
1983	25	3,000	
1984	38	4,500	
1985	57	6,000	
1986	83	9,500	
1987	115	13,000	
1988	146	16,500	
1989	178	20,000	225
1990	210	23,500	
1991	243	27,000	
1992	275	30,000	
1993	314	34,700	
1994	359	39,500	225
1995	411	45,000	
1996	462	50,500	
1997	514	56,000	
1998	571	62,200	225
1999	635	69,000	
2000	705	76,500	

TABLE 5.5.18. Operating Costs for Plutonium Oxide Storage Facilities

Cost Element	Annual Cost, $1000s 30-MT IPSF		200-MT IPSF		200-MT IIPSF	
Direct labor	670		670		860	
Process materials	1450		1450		5080	
Utilities	110		670		700	
Maintenance materials	60		130		150	
Overhead	810		820		1040	
Miscellaneous	130		660		700	
Total	3230	+50% -25%	4400	+50% -25%	8530	+50% -25%

Note: The above costs assume loading or unloading operations at the storage facilities at design capacity. Annual costs during storage only are estimated at 0.7 to 1.3 million dollars per year.

The direct labor and process material costs for the FRP site facilities are similar since these are primarily related to throughput. The independent site facility has higher costs in these categories because of the higher receiving rate at this facility. Differences in the other cost categories are primarily a function of storage capacity and independent site requirements.

Levelized Unit Cost. The levelized unit costs for the reference facilities were calculated on the basis of the three scenarios. Operating cash flows were calculated from Table 5.5.18 assuming a linear relationship with loading and unloading rates. Facilities were assumed to be unloaded at a rate corresponding to the maximum loading rate.

The levelized unit costs calculated using the above scenarios assume private ownership of the FRP-related facilities and government ownership of the independent facility. Tables 5.5.19 through 5.5.21 show the unit costs. Costs for the FRP-related facilities are shown for 10- and 20-year storage. Costs for the independent facility are shown for PuO_2 accumulation ending in 1990 and 2000.

TABLE 5.5.19. Levelized Unit Cost Estimate for the 30-MT FRP Interim Plutonium Oxide Storage Facility

Cost Element	Unit cost, $/kg HM	
	10-yr Storage Scenario	20-yr Storage Scenario
Levelized capital charge	25.00	28.00
Levelized operating charge	3.80	3.70
Levelized total unit cost	28.80 ±20%	31.70 ±25%

TABLE 5.5.20. Levelized Unit Cost Estimate for the 200-MT FRP Interim Plutonium Oxide Storage Facility

Cost Element	Unit cost, $/kg HM	
	10-yr Storage Scenario	20-yr Storage Scenario
Levelized capital charge	35.90	39.60
Levelized operating charge	3.80	3.10
Levelized total unit cost	39.70 ±30%	42.70 ±30%

TABLE 5.5.21. Levelized Unit Cost Estimate for the 200-MT Independent Interim Plutonium Oxide Storage Facility

Cost Element	Unit Cost, $/kg HM	
	Storage to 1990	Storage to 2000
Levelized capital charge	17.00	16.50
Levelized operating charge	2.60	2.70
Levelized total unit cost	19.60 ±25%	19.20 ±25%

5.5.1.11 Construction Requirements for the Interim Plutonium Oxide Storage Facility

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the impact of construction activities.

Project Schedules and Construction Manpower. The schedule for engineering, procurement, and construction of the 30-MT FRP IPSF and the 200-MT FRP IPSF is included in the overall schedule for the FRP. This schedule is given in Section 3.2.3.7. The schedule for engineering, procurement, and construction of the 200-MT IIPSF is shown in Figure 5.5.24.

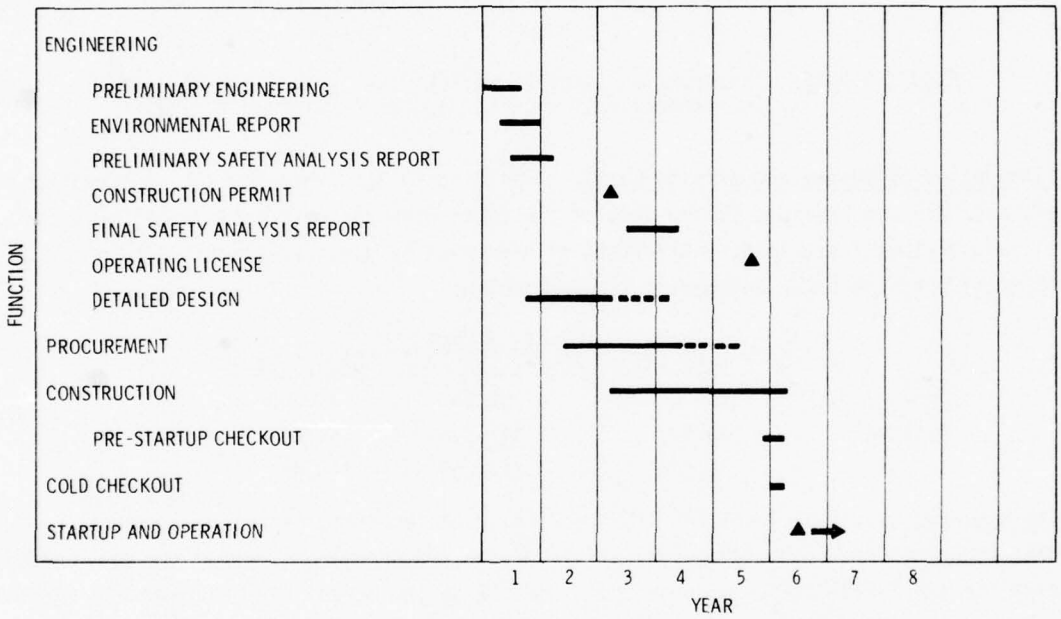


FIGURE 5.5.24. Engineering, Procurement, and Construction Schedule for the 200-MT Independent Interim Plutonium Oxide Storage Facility

The field labor force estimated for the construction of the IPSFs is as follows:

	30-MT FRP IPSF	200-MT FRP IPSF	200-MT IIPSF
Manual field labor	800	4370	4620
Nonmanual field labor	140	800	850
Total field labor	940	5170	5470

The construction man-hours for the 30-MT FRP IPSF and the 200-MT FRP IPSF are distributed in parallel with the labor schedules for the FRP. The construction labor force schedule for the 200-MT IIPSF is shown in Figure 5.5.25.

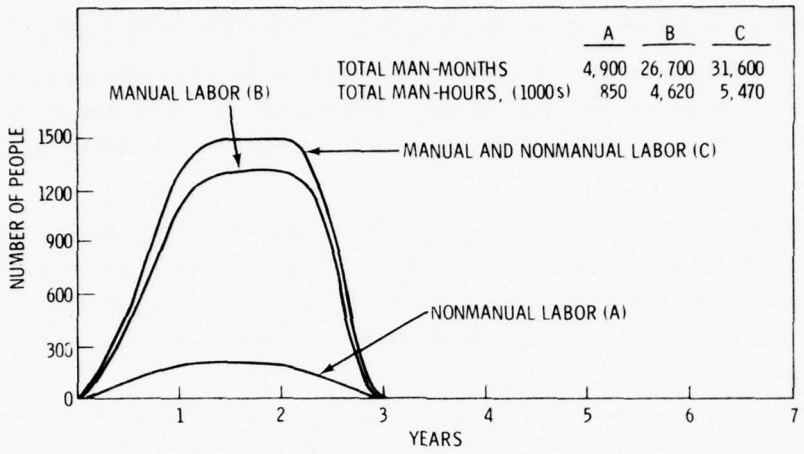


FIGURE 5.5.25. Construction Labor Force Schedule for the 200-MT *Independent Interim Plutonium Oxide Storage Facility*

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, material, and services provided at the site of the IPSF; offsite costs include all services, material, and equipment provided, fabricated, or assembled by outside sources. The distributions of total costs in these categories is shown below:

	Costs, $1000s		
	30-MT FRP IPSF	200-MT FRP IPSF	200-MT IIPSF
Onsite	12,500	69,600	73,600
Offsite	27,500	141,400	151,400
Total	40,000	211,000	225,000

Site Requirements. The 30-MT FRP IPSF requires 2 ha (6 acres) within the FRP site, and the 200-MT FRP IPSF requires 12 ha (29 acres). Thirteen ha (33 acres) are needed for construction of facilities for the 200-MT IIPSF, with an additional 32 ha (80 acres) for constructions storage, work yards, temporary buildings, and labor parking.

Water. Water requirements during construction of the IPSFs are as follows: 30-MT FRP IPSF, 12,500 m^3 (3.3×10^6 gal); 200-MT FRP IPSF, 70,000 m^3 (1.85×10^7 gal); 200-MT IIPSF, 73,800 m^3 (1.95×10^7 gal).

Construction Materials. Materials committed to IPSF construction are:

	30-MT FRP IPSF	200-MT FRP IPSF	200-MT IIPSF
Concrete	6,650 m^3 (8,700 yd^3)	45,900 m^3 (60,000 yd^3)	47,000 m^3 (61,000 yd^3)
Steel	2,000 MT (2,200 tons)	10,500 MT (11,600 tons)	11,000 MT (11,800 tons)
Copper	36 MT (40 tons)	145 MT (160 tons)	160 MT (180 tons)
Zinc	9 MT (10 tons)	36 MT (40 tons)	45 MT (50 tons)
Aluminum	9 MT (10 tons)	27 MT (30 tons)	36 MT (40 tons)
Lumber	350 m^3 (150 MFBM)	2,500 m^3 (1,050 MFBM)	2,500 m^3 (1,070 MFBM)

Energy. Energy resources used during construction are:

	30-MT FRP IPSF	200-MT FRP IPSF	200-MT IIPSF
Propane	106 m^3 (28,000 gal)	587 m^3 (155,000 gal)	621 m^3 (164,000 gal)
Diesel fuel	1,060 m^3 (280,000 gal)	5,870 m^3 (1,550,000 gal)	6,200 m^3 (1,640,000 gal)
Gasoline	720 m^3 (190,000 gal)	3,900 m^3 (1,030,000 gal)	4,125 m^3 (1,090,000 gal)
Electricity			
Peak demand	590 kW	1,700 kW	1,700 kW
Total consumption	540,000 kW	2,950,000 kW	3,100,000 kW

Transportation Requirements. No transportation requirements for the 30-MT FRP IPSF and the 200-MT FRP IPSF have been identified beyond those for FRP construction. For the 200-MT IIPSF, a 4.8-km (3 mile) two-lane paved road must be constructed to the job site for workers' traffic and for material and equipment delivery by truck.

5.5.1.12 Effects of Fuel Cycle Options

The reference process for plutonium oxide storage assumes reprocessing of LWR fuel, recycling the retrieved uranium, and storing the retrieved plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to plutonium oxide storage.

No Recycle. Eliminating the fuel *reprocessing* operation does away with the generation of plutonium product (PuO_2). Thus, no plutonium oxide storage facilities would be required.

Uranium Recycle Only with Plutonium to High-Level Waste (HLW). Sending plutonium to HLW would also eliminate generation of plutonium product (PuO_2), and the plutonium storage facility would not be required.

Uranium and Plutonium Recycle. Some plutonium storage would be required at the FRP as determined by the logistics of transportation between the FRP and the MOX plant. Smooth and continuous operation of the MOX plant would also make storage of plutonium product advantageous. The quantities of plutonium stored at these facilities would be much less than the quantities stored at the IPSFs described in this analysis (probably on the order of only a few months of FRP plutonium product output).

5.5.2 Physical Protection and Safeguard Requirements for Interim Plutonium Oxide Storage

A plutonium oxide storage facility would be classified as a vital area and would be subject to advanced physical protection and material control systems for safeguarding against theft of plutonium and sabotage of the facility. The current safeguards requirements are given in Title 10, Part 70 and 73, Code of Federal Regulations (10 CFR 70 and 10 CFR 73 - see Section 3.9.3). Further guidelines are given in several regulatory guides, principally Regulatory

Guides 5.12, 5.14, 5.15, 5.20, 5.27, 5.43 and 5.44.* Additional safeguards concepts for improving the control and protection of strategic materials such as plutonium have been studied at the Sandia Laboratories. When storing plutonium an engineered safeguards system incorporating intrusion resistant structures and remote control techniques for all normal handling and storage operations is most appropriate. These features would severely limit accessibility to the plutonium by an intruder.(8) Accessibility could be further limited by using measures to delay, such as removal of power to the cranes, deadbolt locking of the storage-well covers, and other disabling actions, all of which could be remotely controlled from a hardened central security control station. By delaying the adversary, time is gained for the arrival of supporting protective forces.

If an attacking group were able to penetrate to a material access area, sabotage of the plutonium storage or handling facilities may be possible or a criticality event might be caused. Should the saboteurs rupture a container of plutonium oxide with explosives or gunfire, radiological consequences would be comparable to those of Accident No. 5.5.5. From the analyses given in Section 5.5.1.9, these events, including the criticality event, would have a very small environment impact, as essentially all of the radiological contamination would be confined to the building interior.

The following characteristics of the interim plutonium oxide storage facility (IPSF) described in Section 5.5.1 would contribute to the safeguarding of the stored plutonium oxide:

- The IPSF building would be a vault-type reinforced concrete structure designed to withstand the effects of all credible environmental and accident conditions. Thus, it would constitute a formidable barrier to potential intruders.
- A loaded storage container would have a surface radiation dose rate greater than 1 R/hr and would weigh several hundred kilograms. The container cover is likely to be sealed or welded and its removal would require an appreciable amount of time. Such conditions would render the container difficult to unload or to move without specialized equipment.
- The operating procedures would minimize the opportunities for diversion by employees. Whenever storage containers are handled in the facility, they would be continuously in view of other operators, including a control room operator by closed circuit television. Radiation alarms would warn of any other unauthorized movements of plutonium.
- The IPSF handling equipment would be capable of being deactivated from the control room, deterring unauthorized operation of the installed equipment.

In addition to these features of an IPSF, material control movements would be monitored by radiation and metal detectors and alarms, or by direct searches at points of exit of personnel, materials, and vehicles to detect attempts to remove plutonium from the material access areas. The physical protection system of the facility is expected to provide prompt detection

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*The regulatory guides are available from the U.S. Nuclear Regulatory Commission, Washington, DC 20555, Attn: Director, Division of Document Control.

of unauthorized entrances and exits and to trigger responsive action by the guard force and other employees. As a minimum, there would be two physical barriers to intrusion from outside the protected area. Current safeguards regulations require that the perimeter be monitored by guard forces or intrusion alarm instruments and be illuminated at all times. Special personnel and vehicle access controls and search and surveillance procedures, including metal, explosive and special nuclear material detectors, and closed-circuit television, must be provided to monitor the status of the material access areas and the storage vault (see Section 3.9.4). The onsite guards must be trained in the use of the physical protection equipment, weapons, and communications. They would have sufficient knowledge of plant equipment and operations to be able to thwart a potential intruder or saboteur. Local law enforcement bodies would be accessible to facility personnel to render aid promptly in response to an attack on the facility. Provision may be made for additional back-up support by Federal forces for defense of a facility of such importance. Aid would probably be primarily for pursuit, capture, and recovery of stolen plutonium.

Because of the IPSF design features and the planned physical security systems, considerable deterrence to theft or terrorist assaults would be provided. Furthermore, the probability of a successful theft in the event of an attack is low. The probability of a successful theft by insiders is also low because of the stringent material control procedures, the limited opportunities for direct access to plutonium, and the monitoring of personnel activities in material access areas.

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5.6 KRYPTON STORAGE

5.6 KRYPTON STORAGE

About 6% of the krypton present in fuel reprocessing plant dissolver off-gas is in the form of the radioactive isotope, krypton-85. During recovery operations, krypton-85 is removed from the off-gas at a rate of 15 MCi/yr. Section 4.9.3 describes the process for recovering krypton from dissolver off-gas and briefly discusses the need for its secure storage once retrieved. This section describes a conceptual krypton storage facility.

5.6.1 Krypton Gas Cylinder Storage

Available technology for krypton storage is limited to storing it as a gas in standard industrial high-pressure gas cylinders until the krypton-85 has decayed to a concentration that would allow its release. The reference fuel reprocessing plant (FRP) krypton recovery system produces about 145 storage cylinders annually. Each storage cylinder initially contains about 1×10^5 Ci krypton-85 (as well as other krypton isotopes and xenon) in a volume of 42.5 ℓ at a pressure of 34 atmospheres (500 psig).

The gas-filled cylinders would be radioactive and would require the use of remote handling techniques. Since krypton is both an inert gas and primarily a beta emitter, radiation hazard from its release normally results only from external exposure, i.e. an immersion dose. However ^{85}Kr decay does include a small component of gamma radiation (0.41% component of 0.514 MeV gamma). In addition, when large quantitites of krypton-85 (or any other beta-particle emitter) are concentrated in a container, penetrating gamma radiation called Bremsstrahlung is generated within the container walls as a secondary effect of absorbing the beta radiation. Thus, substantial shielding is required for the gas cylinder. Although no problems are expected, reliability testing would be needed to establish the long-term effects of radiation, decay products, and thermal conditions on the cylinders.

5.6.1.1 Alternatives for Krypton Gas Cylinder Storage

As mentioned above, the only gas cylinder presently available for krypton storage is the standard industrial type. Alternatives for this technology primarily involve length of storage and location of the storage site. The reference concept described in the following sections specifies a 50-year storage period, which is believed to be well within present capabilities; in 50 years krypton-85, with a half-life of 10.7 years, will decay to 4% of its original activity. Alternatives for length of storage have not been analyzed sufficiently to define an optimum storage period. Location of the reference concept has been limited to a storage site adjacent to the FRP in order to avoid accidents involved in transporting large numbers of gas-filled cylinders.

5.6.1.2 Design Basis for the Krypton Gas Cylinder Storage Facility

The following assumptions were made in the design of the reference facility:

- Krypton-85 is recovered as part of the operation of the reference 2000-MTHM FRP. The storage facility is located near the FRP, and all supporting facilities and services are available from the FRP.

- The reference FRP produces about 145 storage cylinders of krypton-85 gas annually. Each 42.5-ℓ cylinder contains 104,000 Ci krypton-85 gas compressed to 34 atmospheres (500 psig). This is a conservative cylinder loading based on considerations of self-heating temperature limits and cylinder bursting pressure.
- Storage facility construction initially provides 14 storage cells that hold 104 cylinders each, or a total of 1456 cylinders for the first 10 years.
- The storage area increases in 10-year increments to a final total of 42 storage cells holding a total of 4368 cylinders.
- The maximum life of the FRP is assumed to be 30 years. The krypton storage facility is designed to be functional, in terms of leakage containment and recovery, for 50 years after the last cylinder is filled and placed in the storage cells.
- After 50 years of storage, the cylinders are vented to the atmosphere through the facility stack, releasing 4% of the original activity of the gas.
- The storage facility is assumed to be owned and operated by the fuel reprocessor. To assure continuity of surveillance, it may be desirable at the end of the FRP's operating life to pass title of the facility to the Federal government to maintain surveillance responsibility until the last cylinder is vented 50 years after the FRP shuts down.
- A maximum of 0.1% of the krypton in storage is released annually as an operational loss attributable to extremely small leakages from each of a number of cylinders.

Based on the above assumptions, the inventory after 30-years will equal 2.4×10^8 Ci of krypton-85. During the subsequent 20-years the krypton-85 will decay to $\sim 6 \times 10^7$ Ci, and the option to begin releasing contents of cylinders stored for 50 years will be initiated. Figure 5.6.1 shows the krypton-85 inventory in the storage facility as a function of time.

5.6.1.3 Operation of the Krypton Gas Cylinder Storage Facility

The reference facility for storing krypton-85 is equipped to receive, store, inspect and monitor commercial-type gas storage cylinders filled with radioactive krypton gas. The facility also provides the capability to retrieve leaking cylinders and transfer their contents to clean empty cylinders.

Filled cylinders are transported from the FRP to the storage facility in a lead-shielded transfer container specially designed, tested, and approved for that purpose. Upon entering the storage facility, the cylinder transfer container is examined for evidence of damage, radiation streaming, surface contamination, and gas leakage. It is then positioned against a receiving hot cell pass-through port so that the gas cylinder can be transferred into the hot cell. In the receiving hot cell, the cylinder is examined for evidence of leakage. If leaks are found, the cylinder contents are transferred to a leak-tight cylinder. After examination, the cylinder is transferred out of the hot cell and into another shielded transfer cask. This cask is used to move the filled gas cylinder into the gas cylinder storage area, where the cylinder

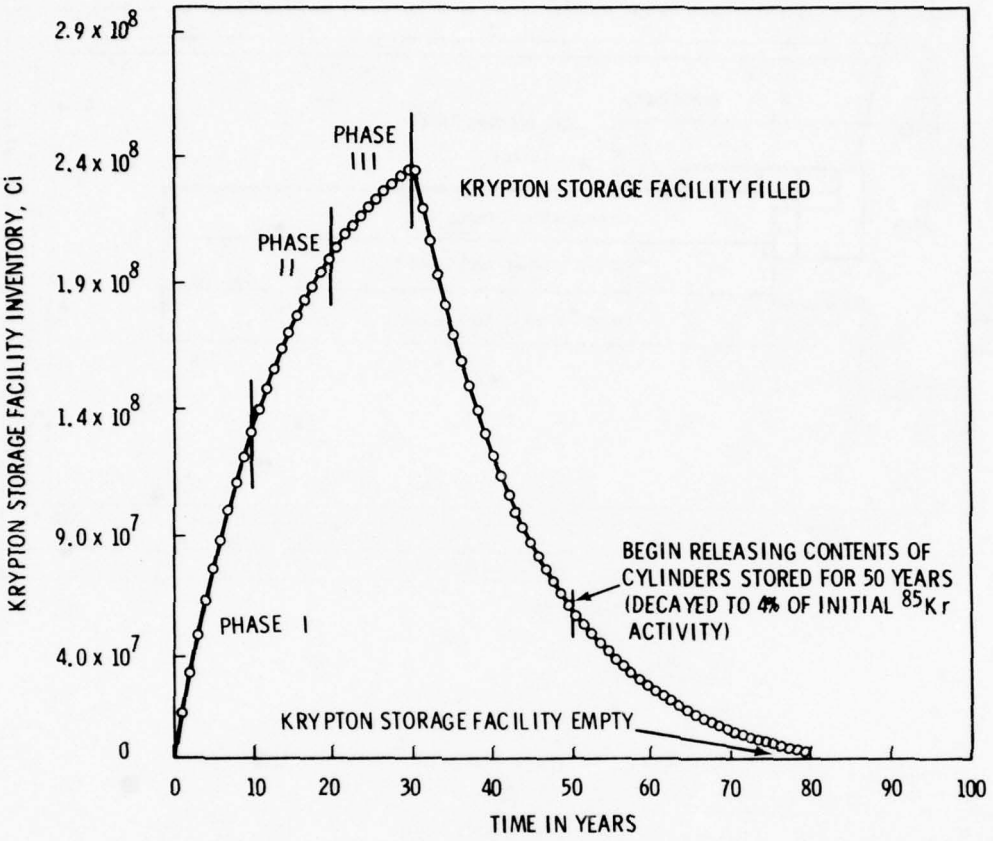


FIGURE 5.6.1. Krypton-85 Inventory in Storage for a 2000-MTHM Fuel Reprocessing Plant

is transferred into one of a series of storage cells. The storage cells are equipped to remove decay heat, monitor for krypton-85 leaks, and provide shielding and security for the gas-filled cylinders.

5.6.1.4 Description of the Krypton Gas Cylinder Storage Facility

Figure 5.6.2 is a plot plan of the reference krypton gas cylinder storage facility located at the FRP site but separated from the FRP by an access road and enclosed within its own fenced exclusion area. Figures 5.6.3 through 5.6.8 show details of the facility.

The krypton storage facility is essentially an independently-operated facility with its own heating and ventilation, water treatment, and emergency electric generating equipment. The FRP supplies primary electrical power, water (potable, process, and fire water), and sanitary sewage disposal.

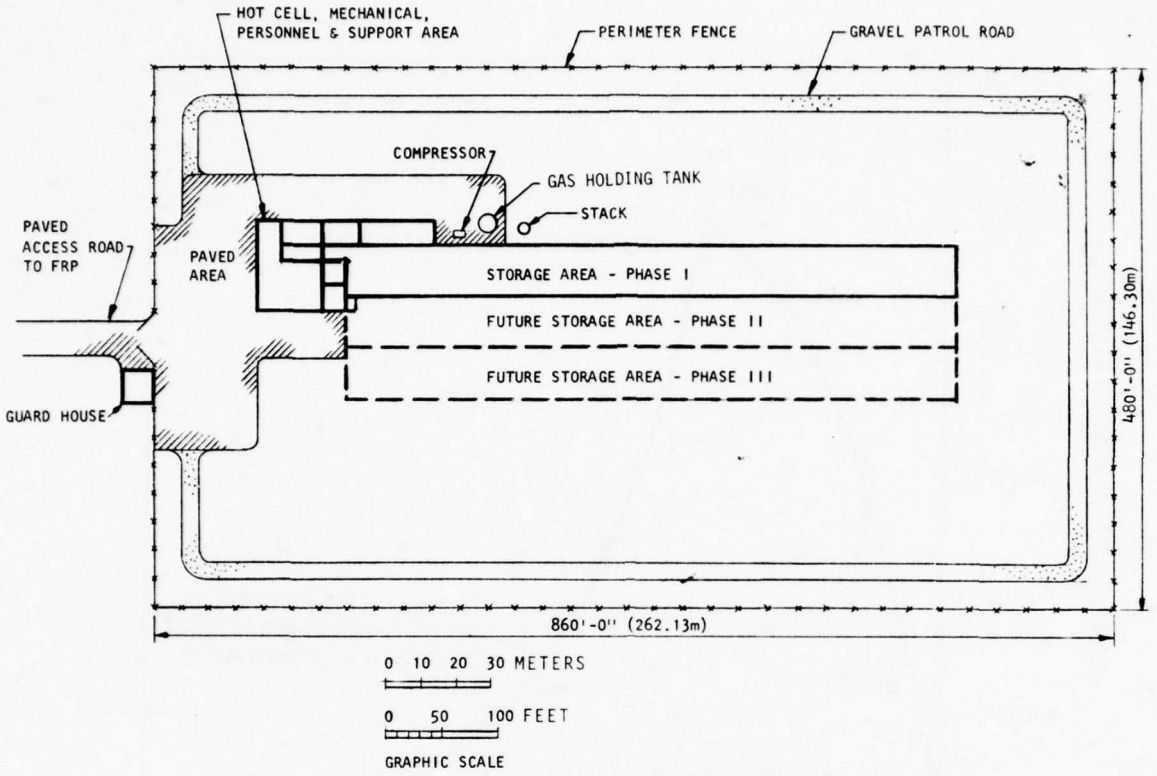
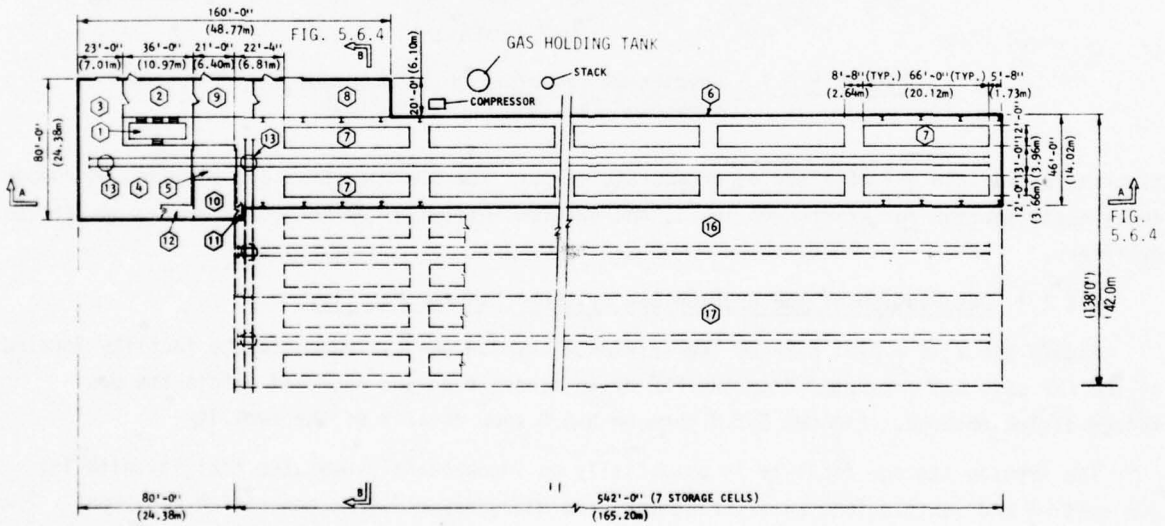


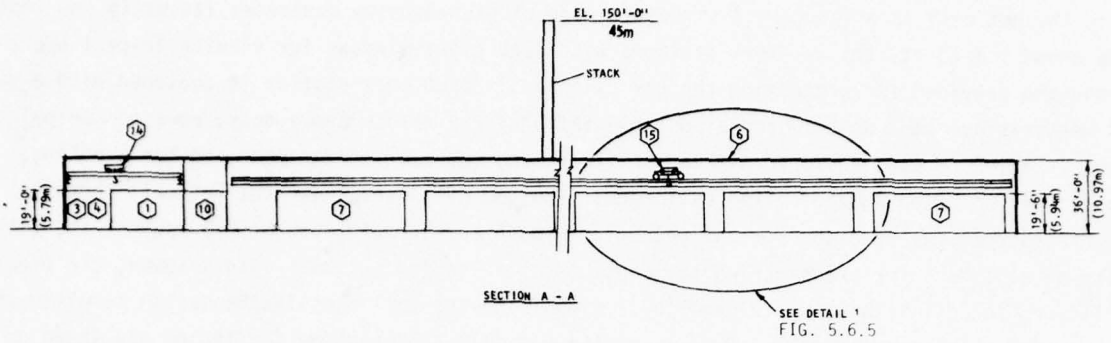
FIGURE 5.6.2. Krypton Storage Facility Plot Plan



1. HOT CELL
2. HOT CELL OPERATING AREA
3. HOT CELL LOADING AREA
4. MAINTENANCE AREA
5. CARRIAGE AIR LOCK
6. STORAGE AREA-PHASE I
7. STORAGE CELL
8. MACHINERY & SWITCH GEAR ROOM
9. OFFICE AREA
10. CHANGE & SHOWER ROOM
11. PERSONNEL AIR LOCK
12. REST ROOM
13. CARRIAGE TURN TABLE
14. 20-TON CRANE FOR OPERATING AREA
15. 20-TON CRANE FOR STORAGE AREA
16. FUTURE STORAGE AREA-PHASE II
17. FUTURE STORAGE AREA-PHASE III

0 5 10 METERS
0 20 40 FEET

FIGURE 5.6.3. Krypton Storage Facility, General Arrangement



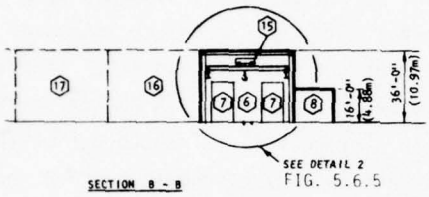


FIGURE 5.6.4. Krypton Storage Facility, Sections A-A and B-B (See Figure 5.6.3 for number key.)

Initial construction includes those facilities shown in solid outline in Figures 5.6.2 and 5.6.3: the receiving hot cell; the mechanical, personnel, and support areas; and the Phase I storage building, which is 14 x 165 m (46 x 542 ft) long. These facilities are standard Category I construction. Exterior walls are precast concrete, and the roofs are insulated metal decking with built-up roofing. All exterior walls and ceilings are insulated and caulked to prevent the escape of krypton to the external atmosphere. Phases II and III of the krypton storage facility will be constructed at 10-year intervals to expand the common storage area. Each phase will comprise an additional storage building of the same size as the Phase I building. The track system for the cask carriage will be extended for each additional storage space. Openings in the common walls will provide access between storage areas.

The storage facility is designed to control radiological hazards and to provide for future expansion of the storage facility. The hot cell used for receiving and examining the gas-filled cylinders is located at the head-end of the storage facility. All incoming cylinders pass through the cell then down a central corridor which provides access to the storage cells located on both sides of the central corridor. Support facilities, such as the HVAC system, air compressor, and other service facilities, are centralized and located beside the hot cell and the storage cells. The interior of the storage facility is divided into an operating area and a storage area. A gas-tight partition with an air lock is used to separate these two areas.

Operating Area. The operating area consists of the receiving and unloading area, rest rooms and change rooms, the building electrical and mechanical room, the hot cell, the hot cell operating area, the entrance to the storage building air lock, and an equipment service and maintenance area.

The hot cell is a Category I structure made of high-density concrete; its walls and roof are about 1 m (3 ft) thick. Work stations with lead glass windows for viewing in-cell operations are provided for processing the gas cylinders. Each work station is equipped with a pair of master-slave manipulators and a control station for a remote heavy duty, powered manipulator. Every station is also equipped with a work table and conveyor system designed for handling, inspecting and capping the filled cylinders. The gas cylinders enter the hot cell through an air lock at the operator's right and exit through another air lock at the back of the cell. Pumping equipment for transferring the contents of a leaking cylinder into a sound, clean gas cylinder; in-cell lights; waste handling systems; and the cell ventilation system complete the gas cylinder preparation cell. Details of the hot cell and handling facilities are shown on Figures 5.6.5, 5.6.6 and 5.6.7.

Storage Area. Each storage area is a long, narrow building, designed as a secondary containment to the cylinder storage cells. A central rail track runs the length of each storage building to provide for movement and positioning of the shielded container transfer carriage. The gas storage cells are arranged along both sides of the track. A 20-ton overhead bridge crane is used for servicing and maintaining each storage cell. The storage building is provided with heat, lights, and ventilation sufficient to meet warehouse storage requirements. This area is normally unoccupied; personnel enter only to install or remove cylinders in the storage cell. Entry of personnel into the storage building is rigorously controlled to minimize exposure to radiation.

The storage cells are reinforced concrete, Category I structures, with walls 0.6 m (2 ft) thick and fully lined with stainless steel. Inside the storage cell the gas cylinders are supported by parallel support bars, spaced to permit flow of cooling air around the cylinders in order to remove decay heat. Each cylinder storage location terminates in a 25 cm (10 in.) dia stainless steel pass-through port, to which is attached a full-port, carbon steel ball valve. Each storage cell is provided with a self-contained air circulation and heat removal system that has supply and return plenums running internally the full length of the storage cell. The fan and chiller units are located between storage units in a tornado-proof concrete housing. Details of the shielded storage cells are shown on Figures 5.6.7 (view B) and 5.6.8.

Access to the cylinder storage positions is through the ball valves mounted on the face of the storage cells. The ball valves provide a gas-tight seal, as well as radiation shielding for operating personnel. The face of the ball valves is designed to mate with the shielded transfer cask to provide a gas-tight seal when loading gas cylinders into the storage cell.

Air circulates in each cell from the top diffuser chamber, down around the stored gas cylinders, and into the bottom diffuser chamber. An externally mounted blower pulls the cooling air out of the lower diffuser chamber, pushes it up through a duct, through a chiller coil and back into the upper diffuser chamber. Butterfly valves are located in the system to:

- maintain a constant temperature inside the cell for heat removal from the cylinders. The maximum heat removal requirement for 145 stored bottles is 1.6×10^4 W.

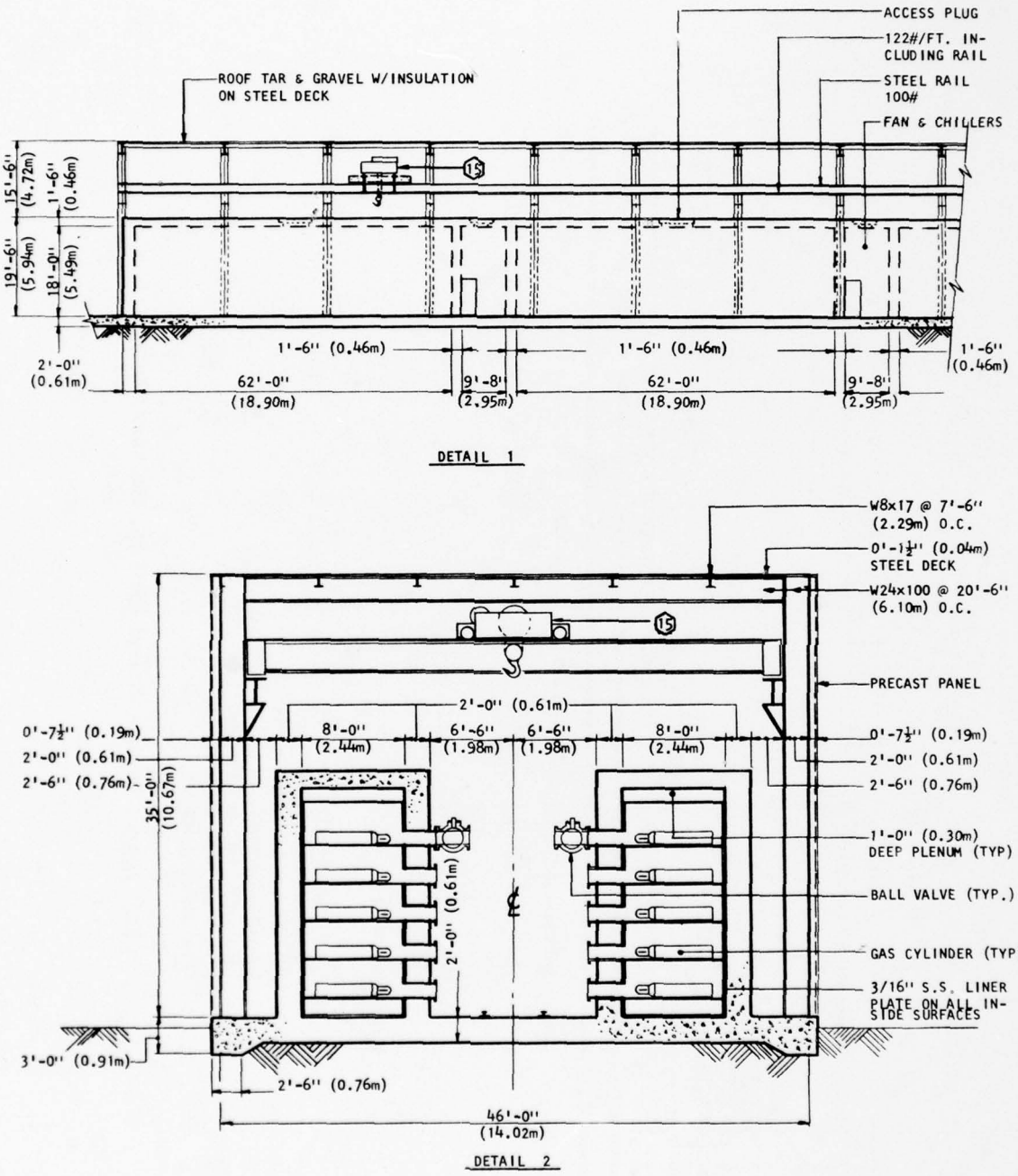
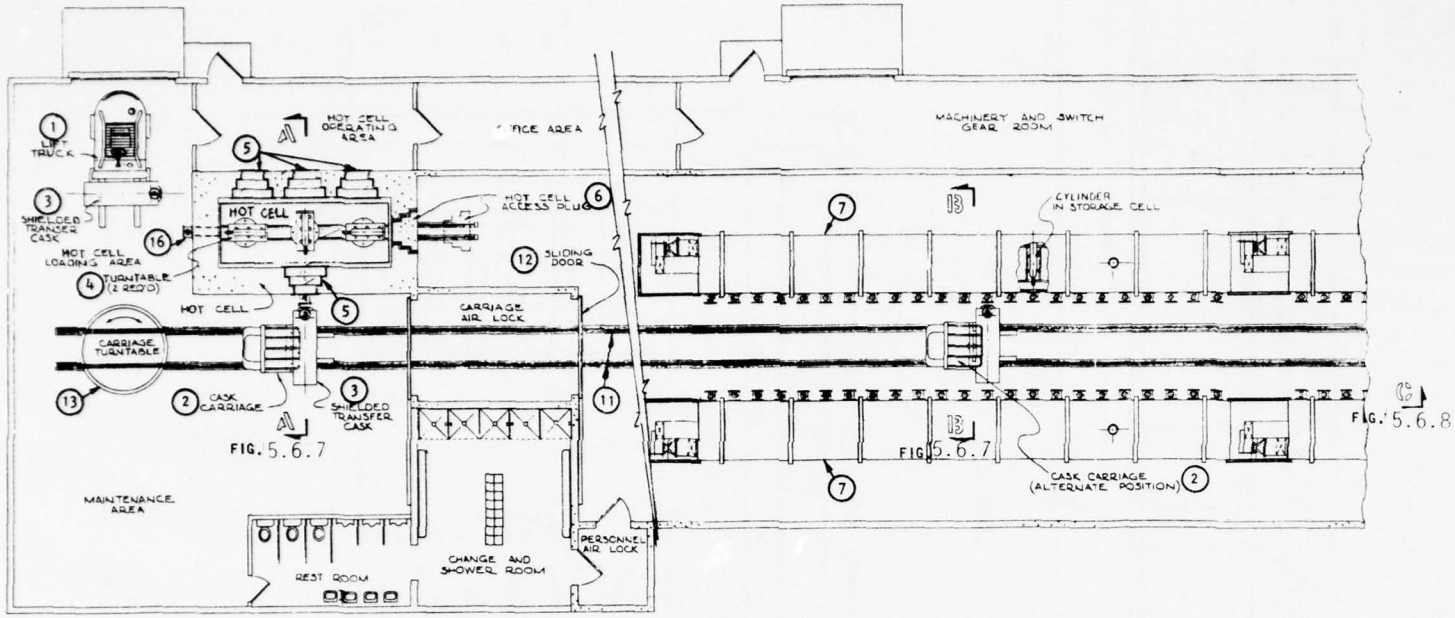
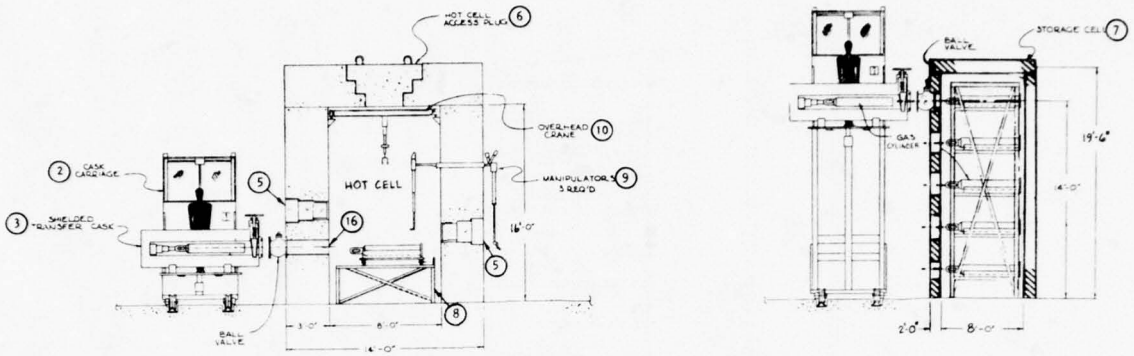


FIGURE 5.6.5. Krypton Storage Facility, Section Details
(See Figure 5.6.3 for number key.)



1. FORK LIFT TRUCK
2. CASK CARRIAGE
3. SHIELDED TRANSFER CASK
4. TURNTABLE IN HOT CELL
5. VIEWING WINDOW
6. HOT CELL ACCESS PLUG
7. STORAGE CELL
8. WORK TABLE IN HOT CELL
9. MANIPULATOR
10. OVERHEAD CRANE WITH POWER MANIPULATOR
11. TRACK SYSTEM FOR CASK CARRIAGE
12. SLIDING DOOR - CARRIAGE AIR LOCK
13. CARRIAGE TURNTABLE
14. OVERHEAD CRANE - OPERATING AREA
15. OVERHEAD CRANE - GAS STORAGE AREA
16. CYLINDER PASS-THRU PORT

FIGURE 5.6.6. Krypton Storage Facility, Additional Details



VIEW A VIEW B

FIGURE 5.6.7. Krypton Storage Facility, Views A and B (See Figure 5.6.6 for number key.)

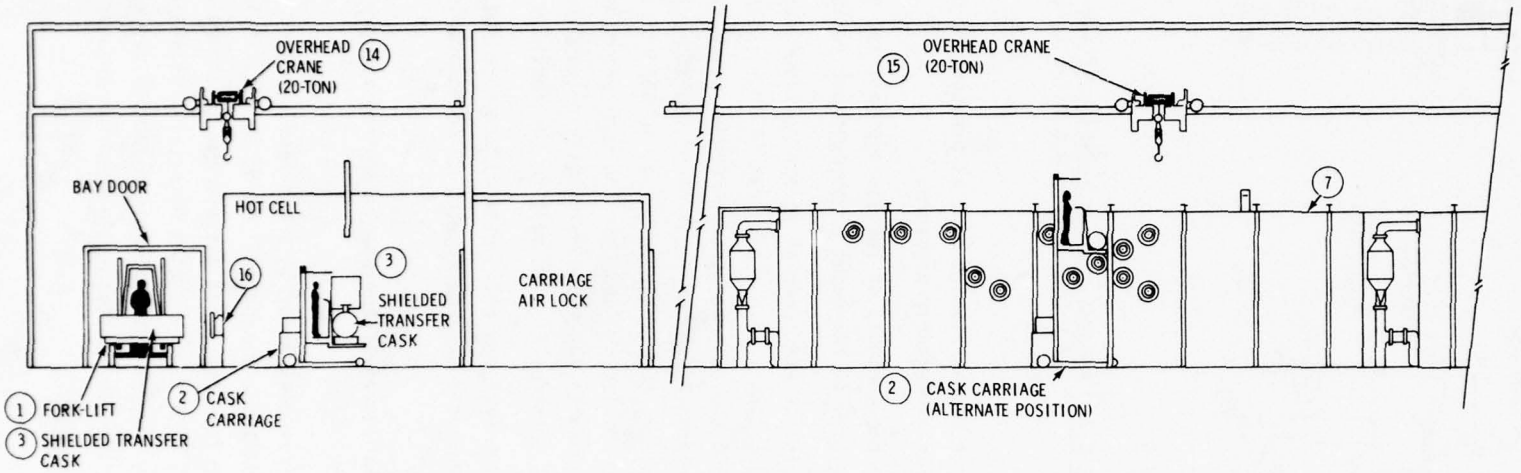
- maintain the inside pressure of the storage cell at pressure of 0.002 to 0.005 atm (1 to 2 in. H_2O) below the outside atmospheric pressure.
- provide a means of purging the contents of the storage cell and of pumping the removed gases into the gas holding tank in the event a gas cylinder ruptures.

Under normal conditions, air for heat removal in the cylinder storage cells circulates within a self-contained, closed system. If a minor leak in a cylinder is detected, the cylinder is sent to the hot cell and the contents transferred to a new cylinder. If a cylinder suddenly ruptures, releasing krypton-85 to the interior of the storage cell, cleanup and purging is required. Should this occur, the isolation valves in the storage cell ventilation system would open to bypass the chiller and evacuate the cell atmosphere to remove the contaminated air. The air would be pumped to the storage facility holding tank, sampled, and either returned to the FRP via a small transfer line or sent to the facility stack for release.

Storage cell instrumentation includes cell internal pressure indicators, cell and ventilation duct radiation level instrumentation, and krypton-85 detectors located in the storage cell and in the cell ventilation duct.

Major Equipment. The major pieces of equipment required for processing and storing the filled cylinders are as follows:

Storage Cylinders. The storage cylinder is a modified standard compressed gas cylinder (DOT Specification 3A-2015). It has a nominal volume of 42.5 ℓ, an inside diameter of 20 cm (9 in.), and a height of 130 cm (52 in.). The gas storage cylinders can be carbon steel. Due to radiological decomposition of seat and stem materials, valves used on commercial cylinders are not acceptable for krypton-85 storage. A special replacement valve, shown in Figure 5.6.9, has been developed and successfully used for shipment of krypton-85.[1]



VIEW C

FIGURE 5.6.8. Krypton Storage Facility, View C (See Figure 5.6.6 for number key.)

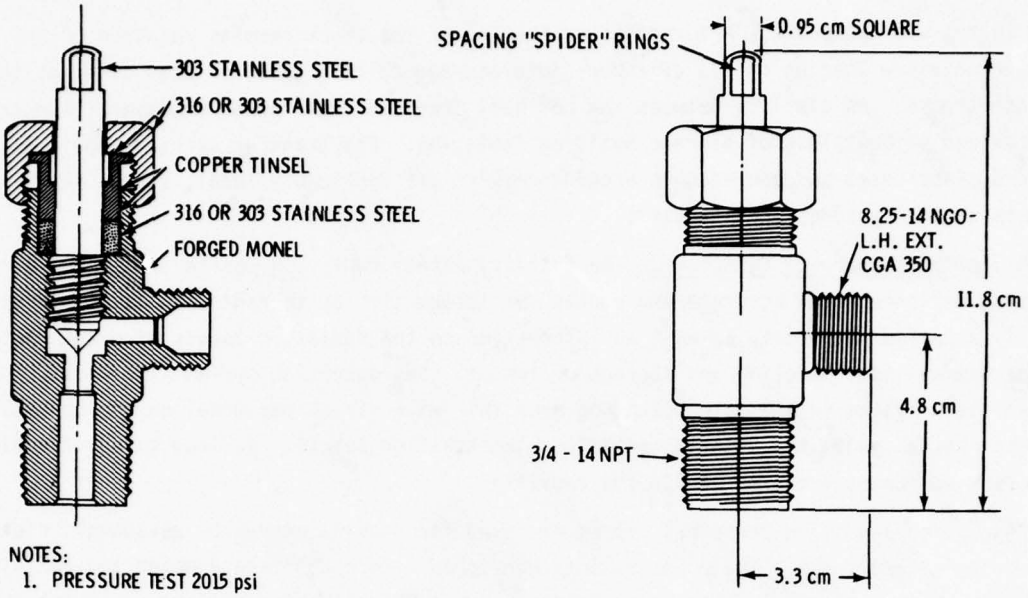


FIGURE 5.6.9. Storage Cylinder Gas Valve

Transfer Cask. The interplant transfer cask is a lead-shielded container designed for transporting filled gas cylinders between the FRP and within the krypton storage facility. This cask is used to transfer the cylinders from the inspection hot cells to the storage cells. Transfer cask features include:

- steel inner and outer shells 0.6 cm (1/4 in.) thick
- a 10-cm (4-in.) thick lead-shielding cylinder between the steel shells
- horizontal positioning on the transfer carriage hoisting frame
- a built-in telescoping hydraulic cylinder for moving the gas cylinders in and out of the transfer cask
- a heavy gas-tight valved closure that prevents radiation streaming from the loading end of the container
- a sealing surface on the valve to mate with both the hot cell and the storage cell to provide a gas-tight connection when transferring a gas cylinder in or out of the shielded container.

The transfer cask is 200 cm (80 in.) long by 41 cm (16 in.) in diameter and weighs about 3 MT.

Transfer Carriage. The transfer carriage is a modified electric-powered (battery-powered) forklift truck which travels on a set of inverted V tracks spaced to give proper interface of the transfer cask with the hot cell and the storage cells (see Figures 5.6.5, 5.6.6 and 5.6.7). The operator rides the forklift portion of the carriage to give him access to the upper storage

ports in the storage cells. A turntable at the end of the track permits rotation of the carriage to allow loading of gas cylinders into storage cells located on both sides of the carriage tracks. An air lock between the hot cell area and the storage area permits entry of the carriage without loss of storage building isolation. The transfer carriage would be designed, fabricated and operated in accordance with all applicable local, state, national and Federal safety codes and standards.

Radiation Monitoring Equipment. The facility safety radiation monitoring system provides operating personnel with accurate and continuous information as to radiation levels in all normally occupied hot areas, as well as information on the radiation levels of plant wastes and the gas cylinder handling and storage equipment. The detection system also provides a central alarm system in the main operating area that will direct personnel to any controlled area that has exceeded the established allowable radiation levels. Various types of radiation monitoring equipment are used within the facility:

- Beta-gamma-sensitive personnel probes are used for general survey of personnel, clothing, equipment and tools. These instruments, equipped with a count-rate meter and audible alarm, are placed in locations that require monitoring of personnel and equipment moving from one area to another or in areas where constant surveillance of contamination is needed.
- Remote monitors are located inside each storage cell, inside the hot cell, and in areas adjacent to these units. The consoles for the remote monitors are located in the central operating area. These detectors provide continuous monitoring of the radiation levels in the complete storage facility. Any radioactivity present in excess of preset meter limits will initiate a visual and audible alarm at the detection location and at the control console. Alarms are reset manually at the console.
- Air monitors are provided for continuous, automatic monitoring of the building's atmosphere. An alarm system provides an audible warning when a predetermined radiation level is reached. These air monitors are located in all areas where personnel might encounter airborne activity.
- Film badges and pocket dosimeters are worn by all personnel inside the storage facility to monitor radiation exposure. The badges and dosimeters are read regularly.

Ventilation System. Outside air is drawn into the operating and storage areas through filters and dampers and is exhausted through a filter system to the building stack. The storage area is maintained at a slightly lower pressure than the operating area. The hot cell is also maintained at a lower pressure than the operating area, and storage cells are maintained at a lower pressure than the storage area. Thus, any air flow between these areas is always from the manned area towards potentially contaminated areas.

For the operating area the ventilation system provides air conditioning with five air changes per hour, recirculating 80% of the air and discharging 140 m^3 of air per minute. In the event of a krypton release the system will switch over to a once-through ventilation and will discharge 700 m^3 of air per minute.

Ventilation in the storage area provides three air changes per hour with a once-through system; air is discharged from each storage building at a rate of 950 m^3/min. Thus, the volume and velocity of air discharged from the stack depends on the number of storage buildings in use. The storage facility stack is 2.4 m (8 ft) in diameter and 45 m (150 ft) high. Table 5.6.1 gives stack discharge velocities and air flow rates for normal operation and in the event of krypton releases, for the reference facility's three storage phases. (The number of cylinders in storage is the smallest during Phase I, increasing to design-basis capacity by Phase III.)

TABLE 5.6.1. Stack Velocities and Air Flow Rates for the Krypton Gas Cylinder Storage Facility

Operating Conditions	Stack Velocity, m/min			Stack Air Flow, m^3/min		
	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
Normal operation	240	440	640	1100	2050	3000
Release in operating area	350	560	760	1650	2600	3550
Release in storage area	240	440	640	1100	2050	3000

Shielding and Remote Handling Equipment. When filled to a pressure of 34 atmospheres, the krypton storage cylinders contain about 104,000 Ci.[2] This results in a calculated radiation dose rate of 700 R/hr at surface and 65 R/hr at 0.9 m (3 ft), requiring shielding of 10 cm (4 in.) of lead or equivalent to reduce the dose rate to 10 mr/hr or less at the surface. The cylinder has a wall temperature of 60°C and generates heat at the rate of 150 W. Procedures are arranged to provide continuous radiation shielding during all steps of the processing and storage of the cylinders filled with krypton-85. All operations are carried out using an overhead crane to move the shielded krypton-85 cylinder transfer cask.

5.6.1.5 Operating and Maintenance Requirements for the Krypton Gas Cylinder Storage Facility

The facility receives and tests krypton cylinders 8 hr/day, 5 days/week. About 145 cylinders are received each year at the facility. The facility is continuously monitored 24 hr/day, 7 days/week, the year around. Maintenance and operating personnel are on call when the facilities are not occupied. During a normal shift, activities include monitoring gas bottles, routinely checking filled bottles for leaks, and sampling cell areas, as well as normal maintenance and replacement functions. Gas bottles and valves are replaced as required. Cylinders in storage are removed and transferred to the hot cell for examination as part of a scheduled quality assurance program.

Where nonroutine operations, instrument readings, and unusual maintenance activities are required, radiation exposure to personnel is rigorously controlled. The gas storage area is normally unoccupied; personnel enter only to install or remove cylinders in the storage area. Entry of personnel into the storage building is limited to prevent overexposure to radiation and contamination hazards.

Staffing. Table 5.6.2 gives estimated staffing requirements for the facility.

TABLE 5.6.2. Krypton Gas Cylinder Storage Facility Staffing Requirements

Job Description	Personnel Required, man-yr/yr
Operators	2
Radiation monitors	1
Maintenance craftsmen	1
Guards	10

Supplies and Utilities. Supply and utility requirements for the krypton storage facility are minimal. An estimated 0 to 7 replacement cylinders will be needed annually. Electricity for the facility is used at a rate of 1500 kW, with an annual requirement of 10^7 kWh.

5.6.1.6 Secondary Radioactive Wastes for the Krypton Gas Cylinder Storage Facility

No secondary radioactive wastes are anticipated during normal operations of this facility.

5.6.1.7 Emissions from the Krypton Gas Cylinder Storage Facility

Facility emissions are characterized in Table 5.6.3. Under normal conditions, releases are not expected to exceed 0.1% of the inventory of the krypton storage facility per year. Over the entire 80-yr operating life of the storage facility, this loss would amount to less than 1.6% of the original activity in the spent fuel. Figure 5.6.10 shows the estimated emissions during the 30-year inventory accumulation and the additional 50-year storage period. The estimated operational loss, combined with a 4% loss due to release of the krypton after being stored for 50-years, and a 10% operational loss in the FRP krypton recovery facility (Section 4.9.3), limits the overall containment to approximately 85% of the ^{85}Kr in the spent fuel. An additional 10 years storage (60 years total) would reduce the final release to approximately 2% of the initial ^{85}Kr and increase the containment to 87% of the ^{85}Kr (dashed line in Figure 5.6.10).

TABLE 5.6.3. Krypton Gas Cylinder Storage Facility Emissions

Emission	Description	Facility Age, yrs	Annual Quantity	^{85}Kr Release, Ci/yr
Gaseous	Stack exhaust air	0-10	5.8×10^8 m^3	See Figure 5.6.10
		10-20	1.1×10^9 m^3	
		20-80	1.6×10^9 m^3	
	Minor accident integrated annual release			None identified
Other	Heat		3×10^3 MW-hr[(a)] (1×10^{10} BTU)	

a. Maximum decay heat (30th year)

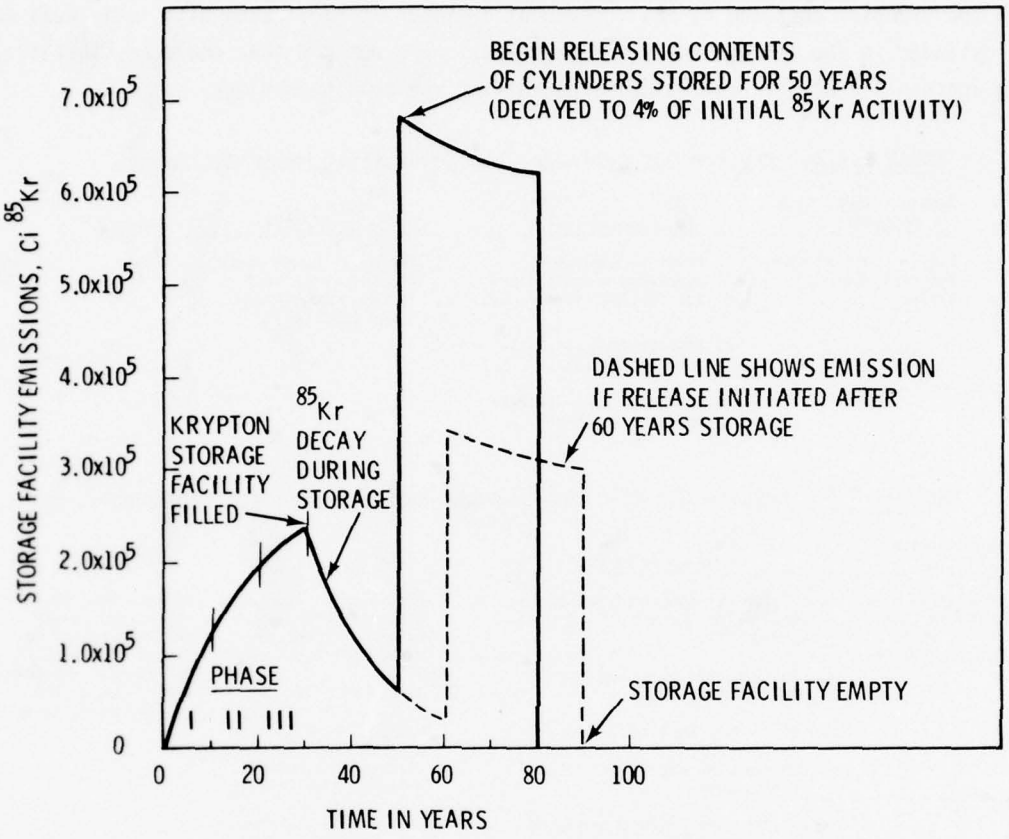


FIGURE 5.6.10. Estimated Krypton-85 Storage Facility Emissions

5.6.1.8 Decommissioning Considerations for the Krypton Gas Cylinder Storage Facility

The krypton storage facility is designed to be functional, in terms of leak containment and cylinder recovery, for 50 years after the last cylinder is filled and placed in the storage cells. Because krypton is an inert gas, decontamination will be a relatively simple and inexpensive task at the end of the storage facilities' operating life.

5.6.1.9 Postulated Accidents for the Krypton Gas Cylinder Storage Facility

Safe storage of krypton gas cylinders is the key design and operational goal of the krypton storage facility. The facility has been provided with highly reliable and redundant normal and emergency cooling, containment, radiation monitoring, and atmospheric protection systems. The system has cells that can be isolated; a disaster that exceeds design basis provisions, though very unlikely, should not disable the entire storage facility.

Tables 5.6.4 and 5.6.5 list postulated accidents for the krypton gas cylinder storage facility. The loss of storage cell cooling system is considered a minor accident with no release of krypton from the storage area. Krypton cylinder rupture in the storage area or cylinder corrosion is considered a moderate accident. The possibility of a cylinder rupture

causing other cylinder ruptures is prevented by limiting transfers to single cylinders transported in the transfer cask and by the individual cylinder storage racks with individual access for each cylinder in the storage cells. No accidents were defined that could be classified as severe accidents could be realistically postulated for this technology.

TABLE 5.6.4. Krypton Gas Cylinder Storage Facility Minor Accidents

Accident Number and Description	Sequence of Events	Safety System	Release
5.6.1 – Loss of storage cell cooling system.	1. Power to substation supplying krypton storage facility interrupted. 2. Storage facility cooling system stops. 3. Emergency power generators are activated.	1. Emergency power diesel generator (several redundant emergency power supplies).	None

TABLE 5.6.5. Krypton Gas Cylinder Storage Facility Moderate Accidents

Accident No. and Description	Sequence of Events	Safety System	Release
5.6.2 – One krypton cylinder ruptures in storage cell or hot cell. Frequency of occurrence ~0.05/yr.	1. Krypton cylinder ruptures during handling in the hot cell or in a storage cell. 2. Leak detected by radiation monitoring system. 3. Cell isolation valves open. 4. Contaminated air is purged to holding tank. 5. Holding tank contents released to the stack at a controlled rate or sent to FRP for reprocessing.	1. Radiation monitoring system provides continuous information as to radiation levels. 2. Damage to other gas cylinders in the storage cell is minimized by restraints in the storage racks and the protective valve caps. 3. The cell is isolated from remaining storage facility. 4. The contaminated air is pumped into a holding tank and released to the stack or returned to the FRP for reprocessing.	Release rate will not exceed normal FRP operational releases of 5.6 kCi/day through the FRP stack. Up to 104 kCi may be released.
5.6.3 – Krypton cylinder corrodes. Frequency of occurrence ~0.05/yr.	1. Valve seat and stem destroyed due to radiological decomposition. 2. Radiation monitoring system detects leaking cylinder. 3. Gas transferred to new cylinder.	1. Monel or equal quality valve. 2. Radiation monitors for leak detection. 3. Pumps and handling equipment are provided for safe gas transfer to new cylinder.	Release rate will not exceed normal FRP operational releases of 5.6 kCi/day through the FRP stack. Up to 10 kCi may be released.
5.6.4 – Krypton cylinder ruptures in operating area or storage corridor. Frequency of occurrence ~0.05/yr.	1. Krypton cylinder ruptured during handling in the operating area or storage corridor. 2. Leak detected and alarmed by monitoring system. 3. Personnel are evacuated from the contaminated area. 4. Krypton is vented to the storage facility stack. 5. Personnel reenter facility and repair damages.	1. Transfer cask minimizes damage to the cylinder 2. Monitors and alarms provide continuous information. 3. Personnel trained for emergency response.	104 kCi of ^{85}Kr is released to the krypton storage facility stack in 0.5 hr. Workers may receive significant exposures.

For purposes of environmental consequence analysis, the material release associated with accident number 5.6.4 in Table 5.6.5 has been selected as an umbrella source term (the concept of an umbrella source term is explained in Section 3.7 - Basis for Accident Analysis). This means that the release from this accident is the largest in its source term category. Accidents are cross-indexed with their appropriate umbrella source term in Appendix A, Section 3. The environmental consequences of this accident are described in DOE/ET/0029.

5.6.1.10 Costs for the Krypton Gas Cylinder Storage Facility

Estimates have been made, in mid-1976 dollars, of capital, operating and levelized unit costs. A complete description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

The capital cost estimate for the krypton storage facility is shown in Tables 5.6.6 and 5.6.7. The costs are tabulated to reflect the construction of the facility in three phases:

Phase I - Initial construction, with storage area for operating years 0-10

Phase II - First expansion, to add storage area for operating years 11-20

Phase III - Second expansion, to add storage area for operating years 21-30

Capital Costs. Table 5.6.6 gives the capital cost estimate for building the initial phase of the reference krypton storage facility. Table 5.6.7 gives the costs for Phase II. Since Phase III is identical in design to Phase II capital costs for each of these phases are the same.

TABLE 5.6.6. Krypton Gas Cylinder Storage Capital Cost Estimate, Phase I

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		20	900	200	1,100
Buildings and structures		860	13,300	10,400	23,700
Bulk materials		160	2,500	2,000	4,500
Site improvements		20	300	200	500
Subtotal of direct site construction costs		1,060	17,000	12,800	29,800
Indirect site construction costs	280	210	4,700	6,200	10,900
Total field cost	280	1,270	21,700	19,000	40,700
Architect engineer services					17,000
Subtotal					57,700
Owner's cost					17,300
Total facility cost					75,000
Estimated accuracy range					±30%

TABLE 5.6.7. Krypton Gas Cylinder Storage Capital Cost Estimate, Phase II

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		5	100	100	200
Buildings and structures		760	12,400	9,100	21,500
Bulk materials		60	800	700	1,500
Site improvements		5		100	100
Subtotal of direct site construction costs		830	13,300	10,000	23,300
Indirect site construction costs	220	170	3,700	4,800	8,500
Total field cost	220	1,000	17,000	14,800	31,800
Architect engineer services					2,400
Subtotal					34,200
Owner's cost					10,300
Total facility cost					44,500
Estimated accuracy range					±30%

Note: Costs for Phase III are the same as for Phase II.

The estimates in the tables cover all capital costs resulting from constructing the reference facility as an independently operated facility located a short distance from, but within the property limits of, the FRP. The reference facility is provided with its own machinery and switch gear room, maintenance area, and personnel areas, including change and shower room, restrooms and offices. Electrical power and water are supplied from the FRP. No portion of the general FRP costs for services, such as laboratories, warehousing, shops, and administration buildings, is allocated to the krypton storage facility.

The total capital cost includes the cost of the transfer cask and all plant-related costs incurred from the start of engineering to the initiation of operation with the exception of working capital.

Operating Costs. The operating costs for the krypton gas cylinder storage facility are shown in Table 5.6.8. Direct labor costs are based on manpower estimates given in Table 5.6.2. Utility costs are derived from requirements described in Section 5.6.1.5. Process materials costs are minimal (cost of storage cylinders are allocated to DOG treatment, Section 4.9.3). Annual maintenance material costs are estimated at 3% of major equipment costs. Overhead and miscellaneous costs are estimated using the standard method described in Section 3.8. The estimates for the miscellaneous items include all unidentified operating costs. The cost of taxes, insurance, and interest are included in the capital charge segment of the levelized unit cost.

TABLE 5.6.8. Operating Cost Estimate for the Krypton Storage Facility

Cost Element	Annual Cost, $1000s	
Direct labor	200	
Process materials	0	
Utilities	200	
Maintenance materials	30	
Overhead	240	
Miscellaneous	230	
Total	900	+50% -25%

Levelized Unit Costs. Table 5.6.9 lists the total levelized unit cost as well as the levelized capital and operating components. The cost calculations assume private ownership of the facility. Capital cost expenditures for expansion Phases II and III are assumed to occur in years 10 and 20. After year 30, the facility is assumed to operate in a simple storage mode at a reduced operating expenditure of $500,000 per year for 50 years until all of the gas cylinders have been vented.

TABLE 5.6.9. Levelized Unit Cost Estimate for the Krypton Storage Facility

Cost Element	Unit Cost, $/kg HM	
Levelized capital charge	13.50	
Levelized operating charge	0.50	
Levelized total unit cost	14.00	±40%

5.6.1.11 Construction Requirements for the Krypton Gas Cylinder Storage Facility

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the impact of construction activities.

Project Schedules and Construction Manpower. Phase I would be built along with the FRP; and construction schedules would be coordinated accordingly. The estimated engineering, procurement and Phase II construction schedule for the Krypton storage facility is shown in Figure 5.6.11. The Phase II construction labor force size, composition and schedule are shown in Figure 5.6.12. The field labor force estimated for the construction of Phase II is:

	Man-hours, 1000s
Manual field labor	1000
Nonmanual field labor	220
Total field labor	1220

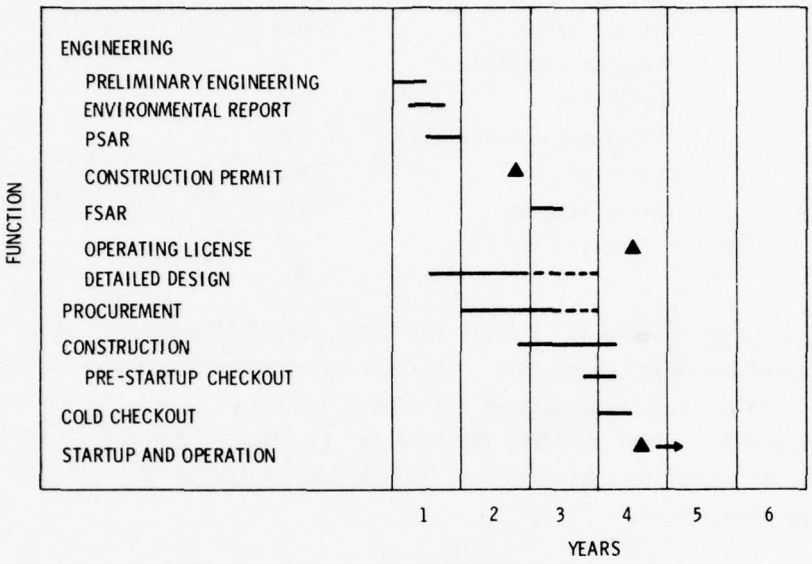


FIGURE 5.6.11. Engineering, Procurement and Construction Schedule for Phase II of the Krypton Gas Cylinder Storage Facility

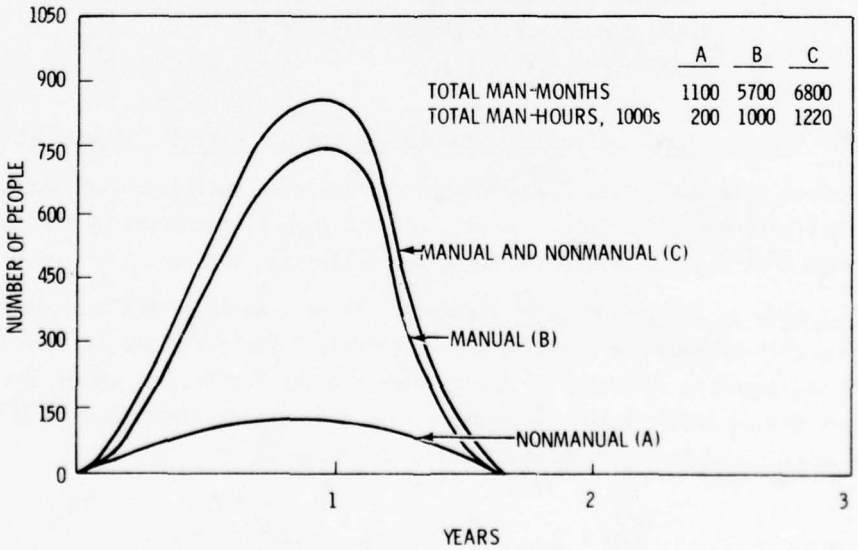


FIGURE 5.6.12. Construction Labor Force Schedule for Phase II of the Krypton Gas Cylinder Storage Facility

Field labor man-hours required for construction of Phase III is the same as for Phase II.

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the storage facility site, while offsite costs are those for all services provided, equipment fabricated or assembled, and material purchased elsewhere. The distribution of total costs in these categories is:

	Costs, $1000s	
	Phase I	Phase II[a]
Onsite	21,000	15,800
Offsite	54,000	28,700
Totals	75,000	44,500

a. Costs for Phase III are the same as for Phase II.

Site Requirements. The Phase I site includes the area required for Phases II and III. Approximately 4 ha (10 acres) are required to be cleared for facility installation. Approximately 6 ha (15 additional acres) are required for construction storage, work yards, temporary buildings and labor parking.

Water. About 19000 m^3 (5 x 10^6 gal) of water are required during the Phase I construction period. During each of the construction Phases II and III 13000 m^3 (3.4 x 10^6 gal) of water are needed.

Construction Materials. Materials committed to facility construction are:

	Phase I	Phase II[a]
Concrete	6,500 m^3 (8,500 yd^3)	5,500 m^3 (7,200 yd^3)
Steel	1,800 MT (2,000 tons)	1,200 MT (1,350 tons)
Copper	36 MT (40 tons)	18 MT (20 tons)
Zinc	36 MT (40 tons)	27 MT (30 tons)
Aluminum	Negligible	Negligible
Lumber	590 m^3 (250 MFBM)	450 m^3 (190 MFBM)

a. Quantities for Phase III are the same as for Phase II.

Energy. Energy resources used during construction are:

	Phase I	Phase II[a]
Propane	176 m^3 (46,500 gal)	119 m^3 (31,500 gal)
Diesel fuel	1,760 m^3 (465,000 gal)	1,190 m^3 (315,000 gal)
Gasoline	1,170 m^3 (310,000 gal)	795 m^3 (210,000 gal)
Electricity		
Peak demand	600 kW	380 kW
Total consumption	884,000 kWh	600,000 kWh

a. Quantities for Phase III are the same as for Phase II.

Transportation Requirements. No transportation requirements for the krypton storage facility have been identified beyond those for the FRP. There is no requirement for a railroad spur to the facility.

5.6.1.12 Effects of Fuel Cycle Options

The reference process for the krypton storage facility assumes reprocessing of LWR fuel and recycling the retrieved uranium and plutonium. The following alternative fuel cycle modes have also been assessed insofar as they relate to krypton storage.

No Recycle. Eliminating the fuel reprocessing operation does away with the generation of dissolver and processing off-gases, such as krypton-85. Accordingly, no krypton storage system is required.

Uranium Recycle Only, with Plutonium to a Federal Repository. This alternative is expected to generate about the same amount of krypton-85 gas as the uranium and plutonium recycle case.

Uranium Recycle Only, with Plutonium to High-Level Waste (HLW). This alternative would also generate about the same amount of krypton-85 gas as the uranium and plutonium recycle case.

5.6.2 Other Alternatives for Krypton Storage

Existing technology limits storage of krypton to pressurized gas cylinders.[3] Other chemical and physical fixation technologies will require additional development. Krypton entrapment methods are being studied at the Idaho National Engineering Laboratory (INEL) and at the Pacific Northwest Laboratory (PNL). Zeolite encapsulation is being investigated at INEL. Zeolites are crystalline aluminosilicates that contain a regular array of pores of uniform size. Krypton will diffuse into the crystalline cages at high temperatures and pressures, while at low temperatures (<150°C) the encapsulated krypton does not have enough energy to diffuse out at an appreciable rate. PNL is studying two additional krypton entrapment methods: dissolution in a glass matrix and entrapment in metal solids during high-rate sputtering.[4] Research is being conducted to determine optimum conditions.

5.6.3 Physical Protection and Safeguard Requirements for Krypton Storage

Krypton-85, a chemically inert radioactive gas, is not expected to be an attractive target for theft and dispersal. During a ground level release at the waste storage facility a threat to the health of the general public becomes insignificant as the gas rapidly disperses.

The dose at the surface of an unshielded cylinder would be about 700 rem/hr when placed in storage but dropping to about 4% of this after 50 years' storage. Remote and shielded storage areas will be required thus reducing the availability of this waste form and making the cylinders relatively unaccessible targets.

Vulnerability to theft while transporting the cylinders from the FRP to the storage facility would be mitigated by the 3000 kg weight of the transfer cask.

A potential exists for purposely rupturing a cylinder during the receipt or during internal transfer operations. The consequences to the public from such acts of sabotage, however, are small as the buildings are designed to allow the release of krypton only through high ventilation stacks. Accident 5.6.4 in which a cylinder is ruptured and its contents released to the atmosphere through the ventilation stack simulates the potential release from an act of sabotage. Approximately 104 kCi of ^{85}Kr might be released over a half-hour period. Such a release could result in significant exposure to workers in the vicinity of the rupture.

A successful sabotage of the cell for storing krypton cylinders does not appear credible. The cell walls would be 0.6 m (2 ft) thick of reinforced concrete. If, however, the walls are breached by an act of sabotage and krypton is released at ground level, the consequences could be serious to workers in the vicinity of the rupture.

Krypton will be stored in a site adjoining the FRP and connected by a short access road. Normal physical protection provided for these parts of the FRP facility are available to secure this waste material. This includes fences or other barriers and a continuous guard force.

REFERENCES FOR SECTION 5.6

1. Safety Analysis Report for Packaging Krypton Shipping Container USA/5958/BL (ERDA-ID), ICP-1077, Allied Chemical Corporation, June 1975.

2. An Evaluation of High Pressure Steel Cylinders for Fission Product Noble Gas Storage, ICP-1044, Allied Chemical Corporation, February 1975.

3. ERDA 76-43, Volume 2, Alternatives for Waste Treatment, 1976.

4. A. M. Platt, Nuclear Waste Management Quarterly Progress Report October Through December 1976, BNWL-2245, P. 4.1-4.6, April 1977.

5.7 SPENT FUEL STORAGE

5.7 SPENT FUEL STORAGE

At this time, because of concerns for potential nuclear weapons proliferation, government policy calls for indefinite deferral of reprocessing of spent nuclear power plant fuel for plutonium and uranium recovery. However no decision has been made as to whether the fuel should be disposed of as radioactive waste. Even if spent fuel should be declared a waste, it will still be a number of years before a disposal repository will be ready for use. In the meantime, the fuel must be safely stored until its disposition is decided and appropriate facilities are available. Methods for interim storage of spent power reactor fuels are considered here.

Storage of spent nuclear power plant fuel in water basins is an established technology that has been successfully and safely applied since the first nuclear power reactor began discharging fuel almost 20 years ago. Storage periods for some of the fuel has exceeded 10 years with minimal degradation of fuel cladding.[1] Long-term storage considerations (storage up to 100 years) and an increased emphasis on safety have prompted investigation of additional spent fuel storage technologies. Table 5.7.1 presents an overview of the alternative storage concepts that have been considered in recent years.

TABLE 5.7.1. Comparison of Fuel Storage Alternatives

Storage Alternative	Confinement Barriers in Addition to Cladding	Means of Heat Removal	Method of Controlling Fuel Cladding Corrosion	Maintenance Requirements	Land Use (Surface)
Unpackaged storage					
Water basin	Water and filters	Forced circulation of basin water	Water quality control	High	Low
Air-cooled vault	Filters	Forced circulation of air	Low temperature	Moderate	Moderate
Packaged storage					
Water basin storage	Water, filters and canister	Forced circulation of basin water	Packaged in inert or noncorrosive medium	High	Low
Air-cooled vault	Canister	Natural circulation of air	Packaged in inert or noncorrosive medium	Low	Moderate
Concrete surface silo (surface storage cask)	Canister	Natural circulation of or conduction to air	Packaged in inert or noncorrosive medium	Low	High[a]
Geologic	Canister, hole liner and filters	Conduction to earth	Packaged in inert or noncorrosive medium	Moderate	Low
Near-surface caisson	Canister and hole liner	Conduction to earth	Packaged in inert or noncorrosive medium	Low	High

a. Estimated to be $\sim$120,000 m^2 per 1500 MT, assuming one MT per storage unit.

The storage methods include both packaged and unpackaged storage. Packaged storage refers to methods where the spent fuel is first sealed in canisters to provide an additional confinement barrier.

Not all of the storage concepts identified in Table 5.7.1 are described in detail here. The ones not described are air-cooled vault storage of unpackaged spent fuel and geologic storage. Air-cooled vault storage of spent fuel is an attractive concept if natural-draft cooling can be employed. However, to reduce the probability of radiation releases to an acceptable level, it is considered essential that effluent air be filtered if unpackaged fuel is cooled in this manner. Since an effective filtration system cannot be provided without forced air circulation, consideration of air-cooled vault storage is confined here to a packaged fuel concept. The geologic storage concept is described in Section 7 as a method for final isolation and is not further considered here.

Although water basin storage of unpackaged fuel is established as a safe and viable technology, concepts employing packaged fuel are of interest for extended storage periods because they provide added confinement and simplified (more passive) cooling systems. However, packaged spent fuel storage is not considered a practical alternative until several years following reactor discharge because the heat generation rate in short-cooled spent fuel would result in unacceptable spent fuel storage temperatures. An optimum period between discharge and encapsulation (packaging) has not been established. For the concepts described here it is assumed that the spent fuel is stored in the nuclear power plant's water basin for a minimum of 6 months following discharge. It then may be transferred to an independent spent fuel storage facility (ISFSF) or remain in the power plant basin. Following an additional 6 years storage at either the power plant basin or an ISFSF, it is sent to a packaging facility for encapsulation. It can then be transferred to a facility for interim storage of packaged spent fuel.

The facilities described here are designed as modular building-block units so that a number of different storage systems can be described with a minimum of facility descriptions. The storage concepts and storage systems described in this section are identified in Figure 5.7.1. The report section where each concept is discussed is also identified in the figure. The facility concepts include:

1. Unpackaged spent fuel storage at a 3000 MT ISFSF with a 1000 MT/yr receiving capacity. This type of storage is also sometimes referred to as "away from reactor" or AFR storage. This concept is described in Section 5.7.1.
2. A modified ISFSF used in combination with a spent fuel packaging facility. Here the ISFSF receiving capacity is increased to 2000 MT/yr and additional surge storage capacity is added. This concept is described in Section 5.7.2.
3. A 2000 MT/yr packaging facility collocated with the modified ISFSF. This concept is described in Section 5.7.3.
4. Four alternative packaged spent fuel storage facilities that can all be expanded in 2000 MT capacity modules up to an ultimate capacity of 20,000 MT. The concepts include packaged fuel storage in

a) water basins (described in Section 5.7.5)
b) air-cooled vaults (described in Section 5.7.6)
c) dry caissons (described in Section 5.7.7)
d) surface storage casks (described in Section 5.7.8).

These storage facilities can be collocated on the same site as the packaging facility or at a separate independent site.

5. An independent site receiving and shipping facility to handle fuel when the packaged storage facilities are located at a site that is separate from the packaging facility. This concept is described in Section 5.7.4.

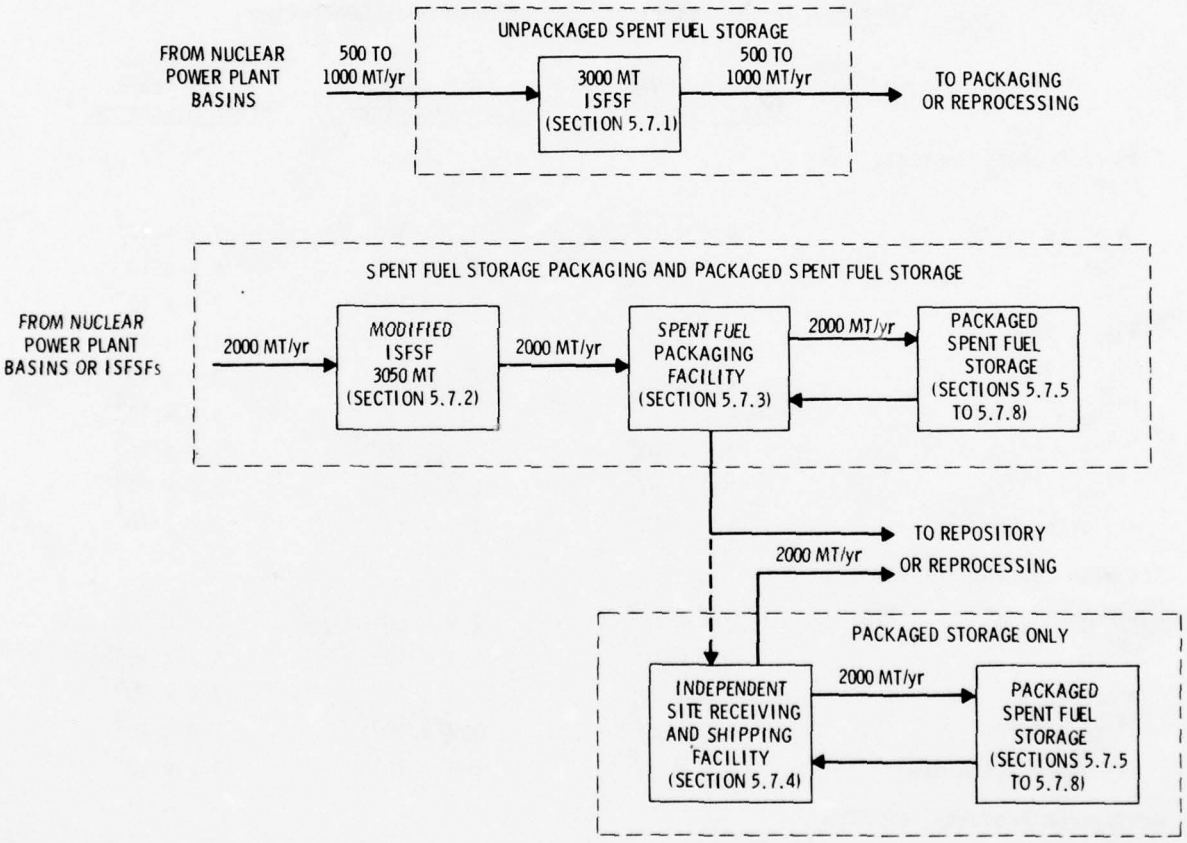


FIGURE 5.7.1. Spent Fuel Storage Concepts and Systems

The individual facilities can be utilized in three different storage systems as indicated by the dashed line boxes in Figure 5.7.1.

1. Unpackaged spent fuel storage in a water basin at an independent site.
2. Combination water basin storage of unpackaged spent fuel, spent fuel packaging, and packaged fuel storage at a single site.
3. Packaged spent fuel storage at an independent site.

Following interim storage, the spent fuel would be shipped to either reprocessing or a final repository. Only the packaged fuel would be eligible for the final repository.

A description of the reference BWR and PWR fuel assemblies is provided in Section 3.3. The average radioactivity and heat generation rates for the spent fuel at 0.5, 3.5 and 6.5 years after discharge is shown in Table 5.7.2. The 0.5-yr aged fuel represents receipts at the ISFSF, the 3.5-yr aged fuel represents average fuel in the ISFSF, and the 6.5-yr aged fuel represents fuel at the time of packaging. These compositions are for once-through cycle fuel. More detailed composition data and data for other ages as well as for recycle fuel is presented in Section 3.3.

TABLE 5.7.2. Radioactivity Content and Heat Generation Rate in Spent Fuel[a]

	0.5 years After Discharge[b]	3.5 years After Discharge[c]	6.5 years After Discharge[d]
Fission Product Content, Ci/MTHM			
^{3}H	4.4×10^{2}	3.7×10^{2}	3.1×10^{2}
^{85}Kr	9.5×10^{3}	7.9×10^{3}	6.5×10^{3}
^{129}I	3.3×10^{-2}	3.3×10^{-2}	3.3×10^{-2}
$^{90}Sr + {}^{90}Y$	1.3×10^{5}	1.3×10^{5}	1.2×10^{5}
$^{95}Zr + {}^{95}Nb$	5.0×10^{5}	4.6	3.9×10^{-5}
$^{106}Ru + {}^{106}Rh$	6.8×10^{5}	8.4×10^{4}	1.1×10^{4}
$^{134}Cs + {}^{137}Cs + {}^{137m}Ba$	3.5×10^{5}	2.3×10^{5}	1.8×10^{5}
$^{144}Ce + {}^{144}Pr$	1.2×10^{6}	8.4×10^{4}	5.8×10^{3}
All other FPs	5.6×10^{5}	5.4×10^{4}	2.6×10^{4}
Actinide Content, Ci/MTHM			
^{239}Pu	2.9×10^{2}	2.9×10^{2}	2.9×10^{2}
^{241}Pu	1.1×10^{5}	9.2×10^{4}	8.4×10^{4}
Other Pu	2.6×10^{3}	2.6×10^{3}	2.6×10^{3}
$^{242}Cm + {}^{244}Cm$	1.8×10^{4}	1.4×10^{3}	1.0×10^{3}
All other actinides	4.5×10^{2}	6.1×10^{2}	1.1×10^{3}
Activation Products, Ci/MTHM			
^{14}C	7.5×10^{-1}	7.5×10^{-1}	7.5×10^{-1}
^{55}Fe	6.1×10^{3}	2.0×10^{3}	1.0×10^{3}
^{60}Co	5.2×10^{3}	3.1×10^{3}	2.1×10^{3}
$^{95}Zr + {}^{95}Nb$	1.1×10^{4}	1.0×10^{-1}	9.0×10^{-7}
All others	1.7×10^{3}	5.6×10^{2}	4.0×10^{2}
Heat Generation Rate, W/MTHM	1.6×10^{4}	2.7×10^{3}	1.4×10^{3}

a. Based on waste characterization Table 3.3.22.
b. Assumed time of receipt at ISFSF.
c. Assumed average age during storage at ISFSF.
d. Assumed time of fuel packaging.

5.7.1 Water Basin Storage of Unpackaged Spent Fuel

In water basin storage of unpackaged (as-discharged) spent fuel, the fuel is stored underwater; the water provides a radiation shield for operating personnel, a transparent medium in which the fuel can be handled and observed, and a heat transfer medium. The fuel decay heat is conducted and convected to the basin water. The heat is then transmitted from the basin water to a secondary cooling loop that dissipates the heat to the atmosphere through a cooling tower.

As mentioned earlier, water basin storage of unpackaged, spent fuel is a well established technology. This storage method is in use:

- at the more than 60 currently operating commercial light water reactors (LWRs) and is planned for all future reactors
- at the major DOE nuclear-related sites at Hanford, Savannah River, and Idaho National Engineering Laboratory
- at the General Electric and Nuclear Fuel Services reprocessing plants.*

This approach is accepted and being used worldwide for fuel storage with minimum environmental impact.

5.7.1.1 Alternatives for Water Basin Storage of Unpackaged Spent Fuel

Facilities used for water basin storage of spent nuclear fuel are similar to one another, with only minor equipment and configuration variations. The storage area is comprised of reinforced concrete pools that may be covered or left open to the storage building. Each pool is lined with stainless steel for water and radionuclide containment, for water chemistry control, and for economy. A concrete-lined pool would not provide a high-integrity water containment structure, would become contaminated with radionuclides (making decommissioning difficult), and would contaminate the water with dissolved chemicals. A mild steel liner would corrode and contaminate the water; liner integrity would, thus, be questionable. Other high-integrity liner materials are generally more expensive than stainless steel.

The spent fuel is usually stored in racks or baskets containing one or more assemblies. The racks, constructed of aluminum or stainless steel, simplify fuel handling and provide nuclear criticality control while allowing as many assemblies as possible to be stored in a given area. Racks constructed of stainless steel, as provided in this study, or borated stainless steel (very expensive) have neutron poison properties that enable closer packing of fuel while preventing criticality. In the past, use of soluble neutron poisons in the pool water has been considered. This practice also allows closely packed storage of the fuel but makes control of the water chemistry more difficult. Fuel density could be increased by stacking racks, but this approach has never been closely investigated.

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*No reprocessing facilities are in operation at these plants. Only the spent fuel storage facilities are currently being used.

Other features of the facility, such as pool configurations and equipment used for heat removal and water treatment, are variable based on economy and engineering preferences.

5.7.1.2 Design Basis for An Independent Spent Fuel Storage Facility

The following assumptions were made in the design of the reference ISFSF facility:

- The facility is an independent facility. All needed requirements and services for facility operation are provided as part of the facility.
- The facility has the capability to receive and/or ship spent LWR fuel at a rate of 1000 MTHM/yr or ∿3.3 MTHM/day for 300 days/yr.
- Ninety percent of the fuel is received in rail casks; the remaining 10% is received in truck casks.*
- Spent fuel is received from the reactor 6 months after discharge and stored 6 years prior to shipment from the facility.
- The facility stores fuel assemblies containing 3000 MTHM in 6 water-filled pools, each with a storage capacity of 500 MTHM.**
- Only fuel from pressurized water reactors (PWR) and boiling water reactors (BWR) is handled and stored.
- The ratio of PWR assemblies to BWR assemblies is 2:3.
- Fuel not confined by a cask is handled underwater.
- Fuel is stored in multiple-assembly, stainless steel storage baskets to minimize pool volume and yet maintain sub-criticality in storage. Spacing is specified for unirradiated fuel with a maximum ^{235}U content of 5 wt% in the PWR assemblies.† This spacing provides an added degree of conservation for storage of the current generation of LWR assemblies with a maximum ^{235}U content in PWR assemblies of ∿3.5 wt%.
- Each water pool can be sufficiently isolated from the remaining pools to permit drainage.
- Radioactivity in the water is normally maintained at $\leq 2 \times 10^{-4}$ Ci/m^3.
- The facility has air locks and a controlled air leakage into the facility.
- A standby air treatment system is available for air flowing through the facility in the event of an airborne release of activity.

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* A similar assumption was made in a report by the U.S. Environmental Protection Agency.(2)

** Regulatory Guide 3.24(3) suggests modular construction with storage pool capacity limited to 500 MTHM for storage of unpackaged spent fuel at an independent spent fuel storage facility.

† According to ANSI N 18.2-1973, "Credit may be taken for the inherent neutron absorbing effect of materials of construction."(4)

- Conditioning of the air other than heating in the winter is not required.
- Identified leaking fuel is isolated to contain fission products.
- The maximum amount of heat generated by the stored fuel is ∿12 MW.
- After the facility has received fuel at an average rate of 500 MTHM/yr for 6 years (3000 MTHM total), fuel that has been at the facility for 6 years is shipped offsite at the average of 500 MTHM/yr and replaced with a 6-month-old fuel from the reactor storage pool.
- Redundant or back-up systems are provided for cooling water and electrical power.

5.7.1.3 Operation of the ISFSF

The primary functions of the facility are to receive and store spent LWR fuel. The sequence of operations normally followed and the areas where they are performed are shown in Figure 5.7.2.

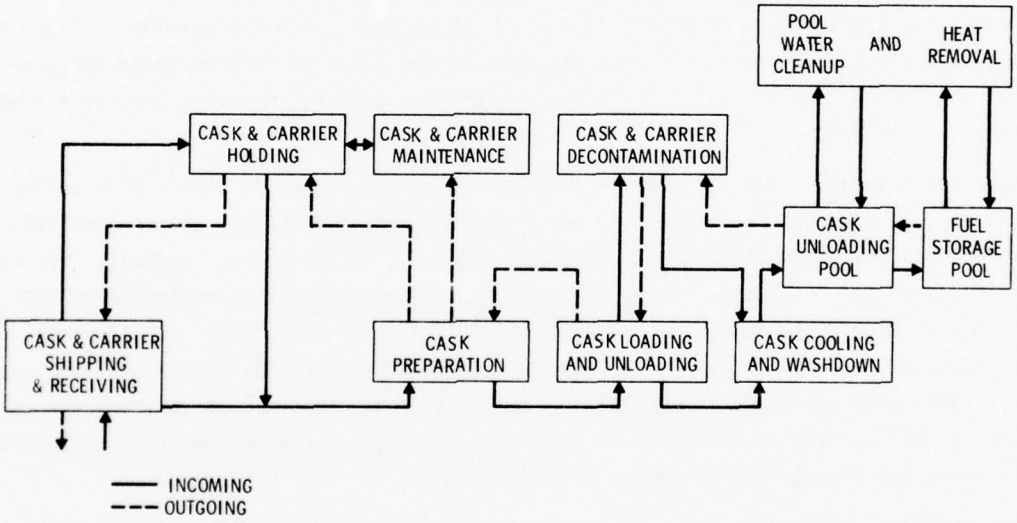


FIGURE 5.7.2. Operations Flowsheet for Water Basin Storage of Unpackaged Spent Fuel

Shipping and Receiving. The fuel shipping and receiving area is able to receive casks containing spent fuel and to ship the empty casks offsite. Also, this area can be used for shipment of fuel to another facility. Irradiated fuel assemblies are received in shielded gas-filled or water-filled shipping casks transported by rail or truck. Upon arrival at the facility, each cask and transport vehicle is identified, inspected for shipping damage, and monitored for radiation level. If the inspection of the cask and carrier shows that normal handling procedures can be followed, the cask-carrier is transferred to the preparation area. Casks with irregularities, misidentification, or damage are sent to the holding area to await unloading by special procedure after communicating with the shipper. Damaged casks, carrier, and peripheral equipment are repaired if possible in the maintenance area. Before casks are shipped offsite, final inspections are made to ensure that the shipment meets Department of Transportation (DOT) regulations.

Cask-Carrier Holding. The cask-carrier holding area provides for temporary storage for the cask (both empty and loaded) and carrier. Cooling of loaded casks in the holding area is normally provided by the system used during transport. Periodic surveillance of the casks is necessary to ensure safe conditions.

Cask Maintenance. The cask maintenance area provides for maintenance and repair of the casks, carriers, and peripheral equipment. Maintenance and repair work are normally performed after fuel has been removed from the cask. Work is limited to routine maintenance and minor repairs except where more extensive work is required to allow cask processing.

Preparation. The preparation area provides for preparation of the cask-carrier for unloading the cask or for shipment offsite. In the preparation area, peripheral equipment, such as solar shields, crash shields, and personnel shields, is removed, checked for contamination, and stored. After the cask is unloaded, the equipment is replaced and the cask-carrier readied for offsite shipment.

Cask Unloading and Loading. The cask unloading and loading area provides for removal of casks containing spent fuel and for the loading of empty casks onto the carrier. It may be economically desirable to load and unload the cask in the preparation area where peripheral equipment is removed from the cask (see above). This can be done, however, only if air movement can be controlled.

Casks are separated from the carrier and its cooling equipment in the cask unloading and loading area. If external contamination levels exceed specified limits, the cask is transferred by the cask handling crane to the cask decontamination pit for washdown. Normally, the cask is transferred to the cask washdown and cooling bay. After the cask is removed from the carrier, the carrier is surveyed for radionuclide contamination and washed if necessary. (Carrier washdown is separate from cask washdown to minimize contamination spread from cask to carrier.) Wash water is collected in holding tanks for subsequent radiation level checks to determine whether additional treatment of the water is needed. Further washdown or sandblasting of small areas may be required to remove contamination.

Cask Washdown and Cooling Bay. The cask washdown and cooling bay provides for preparation of the cask for immersion in a cask unloading pool (CUP). Casks transferred directly from the cask loading and unloading area are washed in the cask cooling and washdown bay to remove the road dirt before transfer to the CUP. Wash water is collected in a holding tank for sampling to determine if treatment is needed.

After cask washdown, the cask primary coolant temperature and pressure are checked to determine the condition of the fuel and the coolant in the cask. Cooling is available if it should be needed. Normally the cask is vented into the process off-gas system, and the primary coolant is sampled and analyzed for gross beta/gamma radioactivity. In the case of a gaseous coolant, the temperature may be sufficiently high to warrant cooling before the gas is tranferred to the off-gas system.

If the cask requires cooldown before immersion in the CUP, the cask is cooled by recirculating water through the cask and a heat exchanger system or, if the coolant is gas, injection

of steam followed by water may be required to reduce the temperature of the fuel gradually. Some suggested temperature limits for cooling system operation are shown in Table 5.7.3.

TABLE 5.7.3. Cask System Temperature Limits for Unloading

	Suggested Limits	Practiced Limits at RBOF[a]
Temperature of water (primary coolant) in cask before venting[b]	93°C (200°F)	93°C (200°F)
Gaseous coolant temperature before venting cask through desuperheater system[b]		538°C (1000°F)[c]
Maximum rate of decrease of fuel temperature when cooled with gas	8.3°C/min (15°F/min)	8.3°C/min (15°F/min)
Temperature of effluents gas from the desuperheater[d]		149°C (300°F)
Temperature of the condensate from condenser (heat exchanger)	93°C (200°F)	93°C (200°F)

a. Limits at the receiver basin for offsite fuel (RBOF) at the Savannah River Plant.
b. The cask must be cooled externally if the internal temperature exceeds the given limits.
c. The 538°C limit for RBOF is apparently a function of design. The suggested limit should be based on the maximum expected temperature in dry casks received at the facility. The maximum temperature of fuel operating in a reactor is ~650°C and temperatures in the cask are not expected to exceed that.
d. The RBOF limit is to avoid damage to concrete and imbedded piping.

Typical temperatures in the NLI 10/24 cask (described in Section 6.2.1.1), in which the primary coolant is helium, are as follows:

- With one cooling system in operation and a maximum design decay heat load (including 1.2 axial peaking factor), the cask temperatures in the stipulated normal conditions of transport would be:

Outer surface	108°C (227°F)
Inner shell	131°C (268°F)
Aluminum basket (max.)	233°C (451°F)
Fuel assembly (avg.)	366°C (690°F)

- When the cooling system is not operating, heat dissipation from the inner shell occurs by conduction through the lead and outer shell, by natural convection, and by radiant cooling

to the environment from the finned outer surface of the water shield jacket. The resulting temperatures in this case would be:

Outer surface	208°C (407°F)
Inner shell	283°C (541°F)
Aluminum basket (max.)	403°C (757°F)
Fuel assembly (avg.)	482°C (899°F)

After cooldown of the cask, the cask coolant is sampled for radioactivity. If the interior of the cask is contaminated or contains leaking fuel assemblies, the cask is flushed with water. Both cooling and flush water is then either circulated through a filter-deionizer system to reduce the contamination to acceptable levels for the CUP or transferred to a holding tank for later disposal or treatment.

Casks containing leaking fuel assemblies are transferred to the CUP when cask and fuel temperatures are acceptable and activity levels in the flush water have stabilized. Casks containing fuel that is not leaking fission products are transferred to a CUP when cask and fuel temperatures are acceptable.

Cask Unloading Pool. The cask unloading pool provides facilities for underwater transfer of the spent fuel from the cask to storage baskets. In the CUP, the cask is lowered into the water and placed on an energy absorbing pad on the bottom of the pool. Limit stops (physical and electrical) on the cask transfer crane preclude moving the cask over areas in which fuel is stored. The fuel storage area is separated from the area where the cask is set down so that a cask cannot tip over and fall on fuel baskets.

The cask lid is removed and transferred to an underwater shelf in the CUP, and the individual fuel assemblies are removed from the cask. An underwater vacuum system is used to remove any material that tends to flake or fall off the fuel assembly as it is withdrawn from the cask, thereby protecting against contamination of the cask. Assemblies with identified leaks are placed in a special container for leaking fuel.

The sound assemblies are transferred to a multiple-assembly storage basket located in the CUP rack. These portable storage baskets are handled with the basket handling crane. When the fuel assembly storage basket is full, the basket is moved from the CUP with the basket handling crane and transferred to the storage basin.

Readily removable components* other than fuel, which may be received with some fuel assemblies (such as control rod clusters and burnable poison rod clusters), are logged and removed from the assemblies and loaded in special containers for disposal.

After the cask has been unloaded in the CUP, the interior of the cask is inspected visually to ensure that all fuel assemblies and nonfuel items have been removed; thorough inspection may require removal of the insert or package used to position the fuel assemblies.

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* Nonfuel components should normally be removed at the nuclear power plant.

Following visual inspection, the cask lid is placed once again on the cask. As the cask is removed from the pool, a ring surrounding the cask sprays high velocity demineralized water to remove pool water and contamination from the exterior of the cask. When the cask reaches the parapet level, the head bolts are replaced in the lid. The cask is then removed from the CUP and lowered into the decontamination pit.

The procedures in an unloading pool when handling casks containing known or suspected leaking fuel assemblies are the same as for casks containing unfailed fuel except that special precautions must be taken to prevent the spread of radioactive materials.* Before the cask is moved to the pool, the pool is isolated. A filtration-deionizer system is temporarily dedicated to receive flow from the CUP that contains the failed fuel. Flow to the heat exchanger from the pool is interrupted to avoid contamination of the heat exchangers.** If the particular leaking assembly is located, it is placed in the failed fuel container. If it cannot be specifically located, all the assemblies in question are placed in a special failed fuel container that permits sampling of the coolant to identify the failed fuel.

After fuel unloading, the empty cask is moved to a decontamination pit with special precautions to prevent spread of radioactivity. Isolation of the CUP is maintained until activity levels in the pool water approach that of the storage basins.

Decontamination Bay. The decontamination bay provides facilities to reduce surface contamination of outgoing casks to levels that meet Department of Transportation regulations and, if required, to reduce surface contamination of incoming casks to levels required for immersion in the CUP.

Incoming Casks. If the contamination level on the surface of an incoming cask exceeds specified limits, the cask is transferred to the decontamination bay for surface cleanup before transfer to the cask washdown and cooling bay or a CUP.

Outgoing Casks. All empty casks returning from the CUPs are transferred to the decontamination bay, where the casks are flushed with deionized water until cavity contamination levels are acceptable. Draining of the pool water contained in the cask may be necessary in the decontamination bay. The exterior surface of the cask is washed until contamination levels are within requirements established by Title 49 of the Code of Federal Regulations.[5] Although high-pressure cleaning solution is used, some casks require cleaning by hand brushing. All washdown water is circulated through a filter deionizer system or is collected in a holding tank for treatment to remove radioactive material. Cleaning materials that cannot be circulated through the filter-deionizer system are collected for evaporation. The head bolts are then tightened to the desired torque and the cask is tested to determine whether or not the gasket is leak-tight. The cask is then moved to the loading bay.

Storage Pools. The storage pools which provide for cooling and shielding of the spent fuel during storage, receive baskets containing spent fuel assemblies. The baskets are stored in

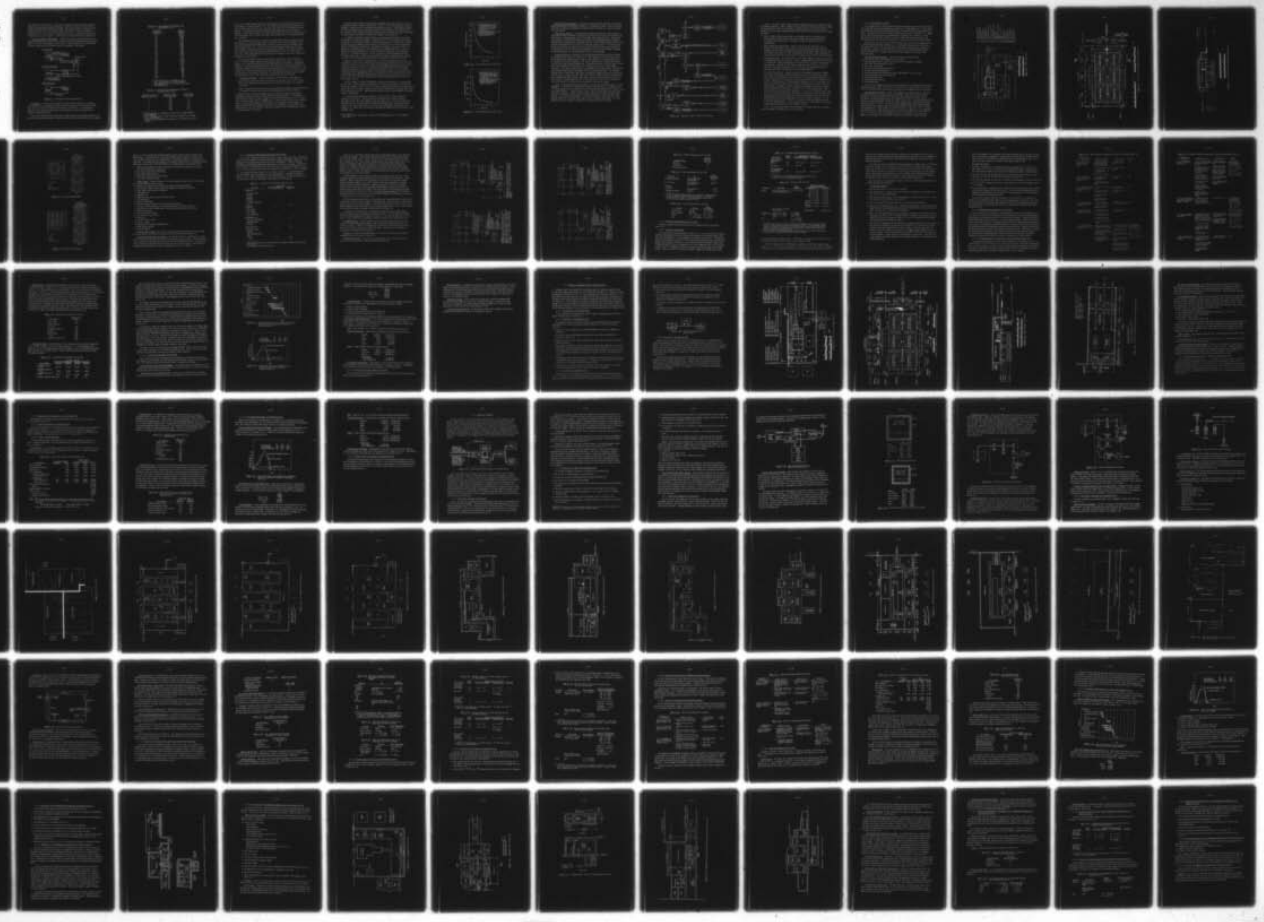
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* Assemblies known to contain leaking fuel elements are usually encapsulated at the nuclear power plant site before shipment.

** If cooling mode is by circulating cooled water through coils in the pool, interruption of cooling would not be required (see text under "Heat Removal" on page 5.7.12).

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racks fastened to the pool floor. These racks are designed to maintain the spacing of the canisters even during extreme natural phenomena. Baskets are stored in the pool pending removal for reprocessing or packaging for longer term storage. Baskets are arranged in the storage pool to avoid first-in-last-out processing of fuel and to limit fuel handling to reasonable levels. Flow of material through the facility can be enhanced by receiving and storing fuel in one pool while fuel is tranferred for further processing from another pool.

Pool Water Cleanup and Heat Removal. The pool water cleanup and heat removal area provides that radionuclides, dissolved salts, particles, and heat be removed from the pool water. Figure 5.7.3 shows a flow diagram of these systems. Slight differences in the requirements for CUPs, storage pools, and transfer aisles are represented in the diagram.

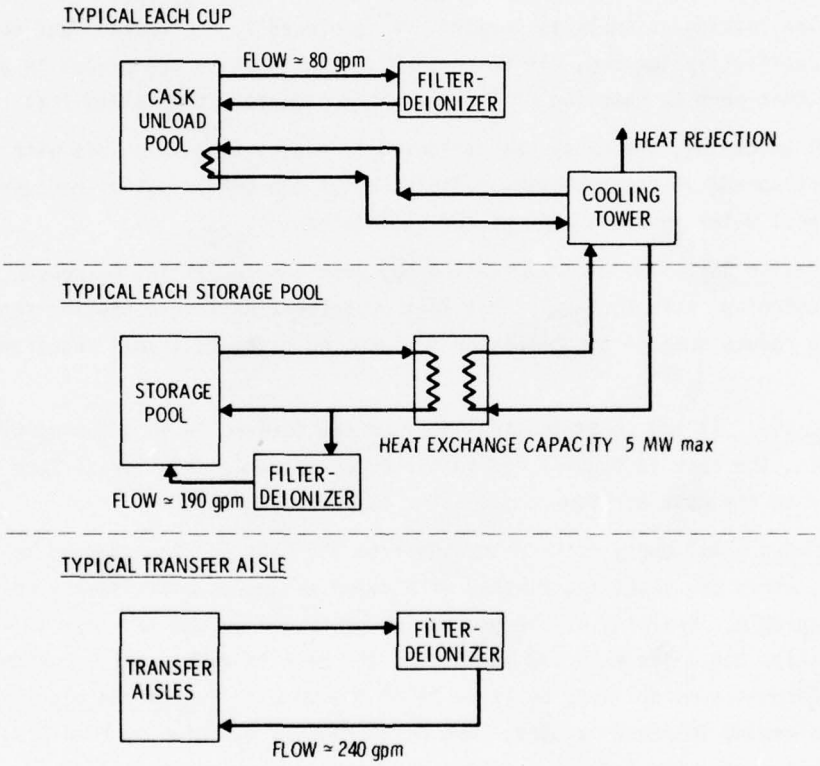


FIGURE 5.7.3. Pool Water Cleanup and Heat Removal

Heat Removal. The water basin storage facility must have the capability to remove at least 12 MW of heat, the maximum heat load on the facility during the filling period (Tables 5.7.4 and 5.7.5), and must maintain the pool water at or below 40°C. A closed system is required for the transfer of decay heat to the environment to minimize the potential for release of radioactive material.

Heat can be transferred from the pool water through either a heat exchanger immersed in the pool or one or more heat exchangers located outside the pools through which pool water is pumped.

TABLE 5.7.4. Heat Generated in Irradiated Light Water Reactor Fuel[a]

Time After Discharge, yr	Heat W/MTHM[b]
0.5	16,940
1.0	10,000
1.5	6,700
2.0	5,170
2.5	3,980
3.0	3,270
3.5	2,690
4.0	2,320
4.5	2,030
5.0	1,820
5.5	1,650
6.0	1,530
6.5	1,440
7.0	1,370
7.5	1,310
8.0	1,250
8.5	1,200
9.0	1,170
9.5	1,140
10.0	1,110
10.5	1,090
11.0	1,070
12.0	1,030
13.0	990
14.0	960
15.0	940
16.0	920

a. Based on average mix of BWR/PWR no-recycle fuel; average exposure = 29,000 MWD/MTHM.
b. Heat generation for 12 to 16 years extrapolated from ORIGEN output.

TABLE 5.7.5. Fuel Heat Load for Water Basin Storage of Unpackaged Spent Fuel[a]

Time After Initial Receipt of Fuel, yr[b]	Quantity of Fuel in Facility, MTHM	Facility Heat Load, MW[c]
1	500	5
2	1000	7.6
3	1500	9.2
4	2000	10.4
5	2500	11.3
6	3000	12.0

a. Based on average mix of BWR/PWR no-recycle fuel; average exposure = 29,000 MWD/MTHM.
b. Fuel is received from the reactor 6 mo after discharge at an average rate of 500 MTHM/year.
c. Total heat load is determined from Table 5.7.4 for quantity of fuel in storage.

In the first of these methods, pipes carry chilled water from a cooling tower through cooling coils immersed in the pool (Figure 5.7.3). This method may be particularly appropriate for pools covering a small area and with a small heat load, such as the CUPs (maximum heat load ∿100 kW). The cooling coils require protection against damage from cask and/or canister movement. Two desirable features of this mode of cooling are that it readily provides cooling for isolated pools and it eliminates the need to pump large quantities of contaminated water out of the pools.

The second method of cooling is expected to be required for large area pools with large heat loads, such as the fuel storage pools. Large quantities of water are pumped from the pools and through the heat exchangers where the heat is transferred to chilled water from a cooling tower (Figure 5.7.3.). The design flow through the heat exchanger for the Allied General Barnwell spent fuel receiving and storage station (SFRSS) is 7.57 m^3/min (2000 gpm) for a heat load of ∿4 MW to maintain pool water temperatures of 40°C.[6] On this basis, a flow of 22.7 m^3/min (6000 gpm) to the heat exchangers is required to remove the 12 MW of heat generated by the stored fuel.

The total heat removal capability of the facility does not have to be available initially. The heat exchanger design could permit add-on capability as needed. A preferable method is one in which each separate pool (500-MTHM capacity) is serviced by a separate heat exchanger. This permits continued isolation of each pool; it also allows the capacity of the add-on heat exchanger to be tailored to the decreasing heat load in the individual pools. For instance, the initial heat exchanger would have a heat removal capacity of at least 5.0 MW and could service each successively filled pool. The additional heat exchanger capacity needed for the 4th year is only 1.2 MW, while that needed the last year is only 0.9 MW.

Filter-Deionizer System. The facility employs a filter-deionizer system capable of:

- maintaining the normal pool water activity level at less than 2×10^{-4} Ci/m^3, the water purity level adopted for the receiving basin for offsite fuel (RBOF) at the Savannah River Plant
- rapidly reducing the activity level in any pool to normal in the event radioactive material is released to the basin from leaking fuel (estimated maximum release of 200 Ci).

A substantial flow to the filter-deionizer system is required to remove the radioactivity introduced into the pool water by surface residue on the fuel assemblies. At the RBOF, a filter-deionizer flow of 473 ℓ/min (125 gpm) is used to maintain activity at 2×10^{-4} Ci/m^3 in a pool having a volume of 1850 m^3 (∿490,000 gal). (A total of about 53 Ci/yr with no leaking fuel is collected by the deionizer system at RBOF.) At the General Electric Midwest Fuel Reprocessing Plant (MFRP), a deionizer flow of 946 ℓ/min (250 gpm) is used to maintain the water activity at $\sim 2 \times 10^{-4}$ Ci/m^3 for a pool with a volume of 2195 m^3 (∿580,000 gal) and with a current fuel load of ∿250 MTHM.

The total volume of water for the reference independent spent fuel storage facility with a 3000-MTHM inventory is about 13,400 m^3 (3.55 x 10^6 gal). If the filter-deionizer system at the MFRP is assumed typical for spent LWR fuel handling facilities, a filter-deionizer flow of 340 m^3/hr (∿1500 gpm) would be required to remove activity introduced to the water from the fuel element surfaces. Additional deionizer capacity would be required to provide rapid cleanup of a pool highly contaminated by a leaking fuel assembly, as discussed here.

To estimate the deionizer capacity necessary to provide rapid cleanup of a pool highly contaminated by a leaking fuel element, a release of 200 Ci* of fission products to the pool was assumed. This release corresponds to that occurring should 1% of the fuel rods in a PWR assembly fail during shipment or after receipt at the facility and 1% of the fission product activity (excluding gases) contained in the elements is released. This large a release is thought to be extremely unlikely. The storage facility at the MFRP, Morris, IL, has so far identified no leaking assemblies.(1) Failure rate during irradiation in a nuclear power reactor is 1 in 10,000 irradiated;(7) the less severe water basin environment would have a much lower failure rate. In addition, even estimates of severe accidents which are outlined in Table 5.7.5 are not expected to release 200 Ci of activity to the water basin or CUP.

Release of 200 Ci in a CUP (assumed volume of 760 m^3 or 200,000 gal) would result in a concentration of ∿0.25 Ci/m^3. Several days could be required to remove the activity from such a release, as Figure 5.7.4 shows. To maintain normal throughputs and assuming that one CUP has an activity level of 0.25 Ci/m^3, the latter unloading pool would have to be isolated, cleaned and placed back in service within ∿4 days following a failure. This would result in an additional flow of approximately 1000ℓ/min (∿300 gpm) to the filter-deionizer system. Even faster cleanup may be desirable; RBOF experience has shown that at pool water activity levels of 10^{-2} Ci/m^3, fresh air masks are required for operating personnel because of the activity that spreads to the air.

A 200 Ci release in a 1890 m^3 (500,000 gal) storage pool would result in a concentration of ∿0.1 Ci/m^3. Greater flows would be required to clean these larger pools in the same time period; for instance, as Figure 5.7.5 shows, five-day cleanup would necessitate a filter-deionizer flow of 1500 ℓ/min (∿400 gpm). However, large releases of radioactivity to storage pools would be less likely than to a CUP. Rapid cleanup would be desirable from the standpoint of reducing spread of contamination.

A filter-deionizer system with a capacity of 340 to 410 m^3/hr (1500 to 1800 gpm) is required for the facility. The system consists of multiple units to permit backflush and regeneration of some filter-deionizer units while others are on line, and to permit the dedication of units for rapid cleanup of severely contaminated pools. Pools that have been filled with fuel and isolated are normally serviced by a dedicated filter-deionizer unit (Figure 5.7.3). Wastes from filter backflush and deionizer regeneration are directed to a waste treatment system.

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* For a PWR assembly 6 months after discharge, 29,000 MWD/MTHM exposure, at a 35 MW/MTHM power level.

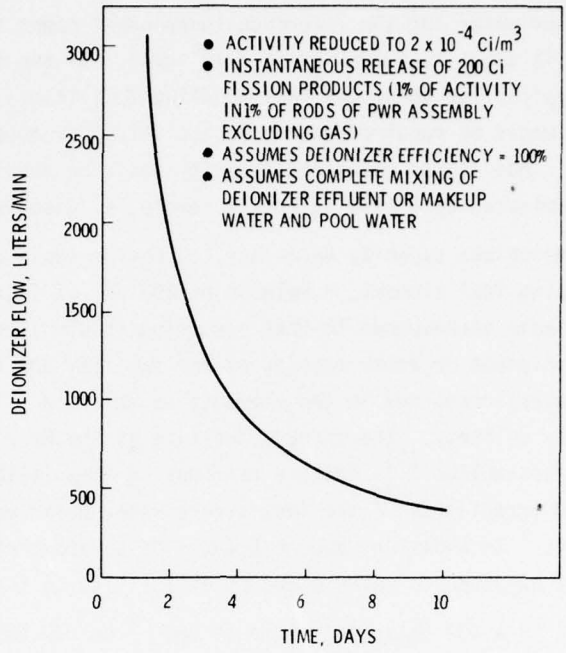


FIGURE 5.7.4. Filter-Deionizer Flow, 760 m^3 Pool

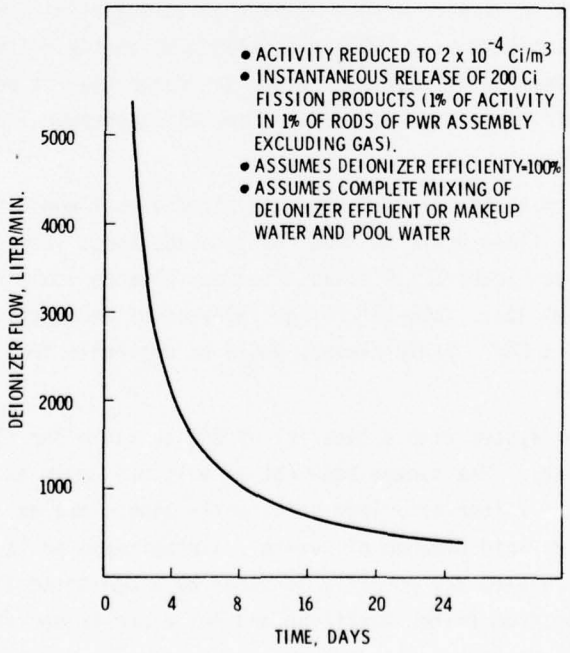


FIGURE 5.7.5. Filter-Deionizer Flow, 1890 m^3 Pool

Waste and Effluents Handling. The waste and effluents handling facilities differentiate between nonradioactive and radioactive materials. As appropriate, gases, slurries, solutions, and solids are treated then packaged for shipment offsite for disposal, or they are released to the environment.

Nonradioactive Materials. Nonradiological effluents associated with interim storage of spent LWR fuel consists of water in both gaseous and liquid form, various solid materials, and ventilating air. Nonradioactive water is an effluent from the cooling towers. Solid wastes include sludge from the sanitation system and various other uncontaminated solid materials associated with the operation of a production facility. The ventilation system for the facility provides once-through air flow, with the air exhausted through a stack. Air flowing through the facility picks up small quantities of heat and moisture and possibly some radioactivity. If radioactivity levels rise above release guidelines, the air is passed through a treatment system to remove particles and iodine before release to the atmosphere.

Radioactive Materials. Operations that generate radioactive wastes in the fuel receipt and storage facility are shown in Figure 5.7.6. Some radioactivity on the exterior surfaces of fuel elements and assemblies arises primarily from activation of structural materials of the assemblies and reactor components. Part of this radioactivity is released into the pool water during storage and handling operations. Radionuclides present in the pool water are also due to leaks (leaching through defects in the cladding) or failure of the fuel elements themselves. Pool cleanup systems (filters, ion-exchange resins, vacuum cleaners) are provided to continuously remove these radionuclides from the circulating pool water. The recovered radionuclides are concentrated, immobilized, and eventually shipped offsite as a nontransuranic (non-TRU), waste. Liners, pits, and sumps are provided to contain any water seeping from the pool or leaking from process piping. Such water is either returned to the pool, treated as a non-TRU waste, or released from the site; in the latter case, it must first be established that concentrations of radionuclides above regulatory limits are not present.

Gases. During normal operation ventilating air for the facility exhausts directly to the atmosphere. In the event of a radioactivity release to the ventilating air, however, the air is directed through a filter system consisting of high-efficiency particulate air (HEPA) filters, and charcoal adsorbers. A process off-gas system is used to treat off-gas from cask venting, leaking fuel assemblies, and other areas with high potential for release of gaseous fission products. This process off-gas system is in continuous operation. Only noble gases (^{85}Kr) and small amounts of tritium and iodine leave the site as gaseous radionuclides. The spent adsorbers and filters eventually become solid non-TRU waste for offsite disposal.

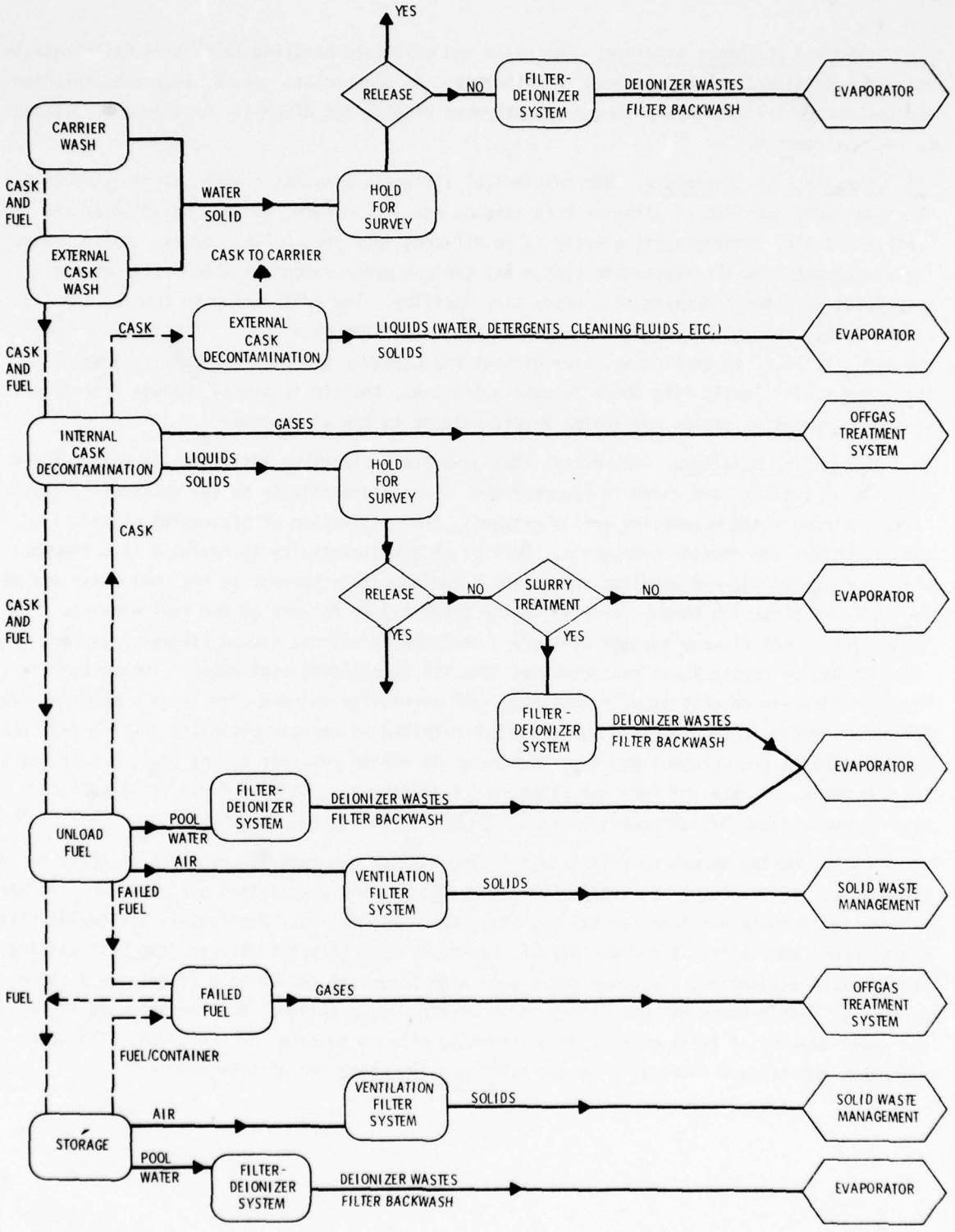


FIGURE 5.7.6. Radioactive Waste from Spent Fuel Handling

Liquids. The various liquid streams containing radioactive material are treated to remove the radioactive material. Water is treated by passing through a filter-deionizer system. Water or other radioactive liquid is concentrated by evaporation before ultimate solidification. The various kinds of liquid radioactive wastes at the spent fuel water storage basin are enumerated below:

- Water from the Filter-Deionizer System. Waste streams that can be treated by the filter-deionizer system include cask-carrier washdown, cooling and flushing water, and leakage from the fuel pools. This water is reused as makeup water for the storage pools.
- Water (Steam) from the Evaporator. Water (as steam) from the evaporator is discharged to the environment. Waste streams treated by evaporation include the water-detergent solutions used to decontaminate the casks and the water-chemical solutions used to periodically backflush the filter and regenerate the deionizer. Minor quantities of radionuclides are entrained in the evaporator discharge and are released to the environment.
- Cask Decontamination. An estimated 1.9 to 3.8 m^3 (500 to 1000 gal) of water is required to decontaminate each cask; this water, which is contaminated with cleaning solution as well as radioactivity, cannot be treated by the filter-deionizer system and is concentrated in the evaporator. Assuming that 1890 ℓ/min (500 gpm) are used for each truck cask and 3785 ℓ/min (1000 gpm) are used for each rail cask, the cask decontamination process generates about ∿760 m^3 (200,000 gal) for each 500 MTHM received.
- Filter-Deionizer Backwash. The water used for filter backwash and deionizer regeneration usually contains small amounts of chemicals for aid in filter-deionizer cleanup and is sent to the evaporator. The amount of water requiring evaporation depends on the flow rate through the filter-deionizer system and the condition of fuel introduced to the facility. RBOF experience is that during normal operation with a filter-deionizer flow rate of 0.48 m^3/min (125 gpm) for the ∿1860 m^3 (∿490,000 gal) basin, filter backflush is required after a throughput of ∿3800 m^3 (10^6 gal) of pool water and deionizer regeneration is required after a throughput of 60,000 m^3 (16 x 10^6 gal) of pool water. Water used for filter backflush and resin regeneration is 4.5 to 7.6 m^3 (1200 to 2000 gal) and 49 to 57 m^3 (13,000 to 15,000 gal), respectively. Assuming that filter-deionizer systems for larger pool volumes have cleanup cycles similar to the RBOF system, the waste water generation would be directly proportional to the filter-deionizer flow rate. For the normal filter-deionizer flow of 340 m^3/hr (1500 gpm) the waste water generation would be 24 m^3/day (∿6400 gal/day). In the event of failed fuel, filter backwash and deionizer regeneration would probably be at more frequent intervals.

Solids. Solid radioactive wastes (failed equipment, maintenance materials, and general trash) are packaged for shipment offsite as non-TRU waste.

5.7.1.4 Description of the ISFSF

The reference facility for water basin storage of unpackaged spent fuel is located within a security fence enclosing approximately 8 ha (20 acres). An additional 2 ha (5 acres) outside the secured area are used for water disposal ponds, the administration building, and parking areas. These plant facilities are centrally located within a 40 ha (1,000 acre) site. Support, utility, and service facilities are provided within the secured area. Figure 5.7.7 shows the plot plan of the facility; Figures 5.7.8 and 5.7.9 show plan and section views of the fuel storage basins for this facility; Figure 5.7.10 shows a plan view of the receiving area.

The main plant consists of a cask and fuel handling area, the main fuel storage basin, and a radioactive waste and water treatment area. The structural features of these facilities are summarized in Table 5.7.6; the items which are required to meet Category I standards are so indicated. Category I specifies design and construction to withstand maximum credible natural disasters such as tornado winds, missiles, and earthquakes as specified by NRC Regulatory Guides.

Cask and Fuel Handling Systems. Cask and fuel handling systems include:

- cask-carrier movers (donkey engine and truck-tractor)
- cask preparation and air lock (including crane for cask peripheral equipment)
- cask, fuel, and basket handling cranes
- wet or dry cask cooldown
- cask wash, cooling, and decontamination
- carrier wash and decontamination
- two cask unloading and loading pools (CUPs) approximately 15 m (50 ft) deep
- fuel inspection and failed fuel handling
- canister transfer canal
- cask and equipment storage
- miscellaneous tools.

A two-rail cask unloading station with two parallel bays for cask preparation and cask off-loading and loading, either from rail cars or truck trailers, is also provided. The facility has a cask and fuel handling system capacity equivalent to 1,000 MTHM/yr received or shipped.

Fuel Storage Basin Systems. The main fuel storage basin is divided into six individual storage pools, each with a storage capacity of 500 MTHM. Gates permit isolation of each pool area. The fuel storage basin has a total pool water surface area of about 1365 m^2 (14,700 ft^2) (excluding transfer canals) and a depth of 9 m (30 ft). The space required for fuel storage is reduced substantially by the use of fuel storage baskets constructed of stainless steel 0.64 cm (1/4 in.) thick. The use of multiple-assembly baskets (four pressurized water reactors [PWR] or nine boiling water reactor [BWR] assemblies) simplifies transport from the cask unloading pools. These baskets are shown in Figures 5.7.11 and 5.7.12. It is estimated that each of the six storage pools must have an area of 230 m^2 (2480 ft^2), or the dimensions 18.9 x 12.2 m (62 x 40 ft), to accommodate its capacity of 500 MTHM in a criticaly-safe manner. This estimated area includes the transport aisle and space to handle and place

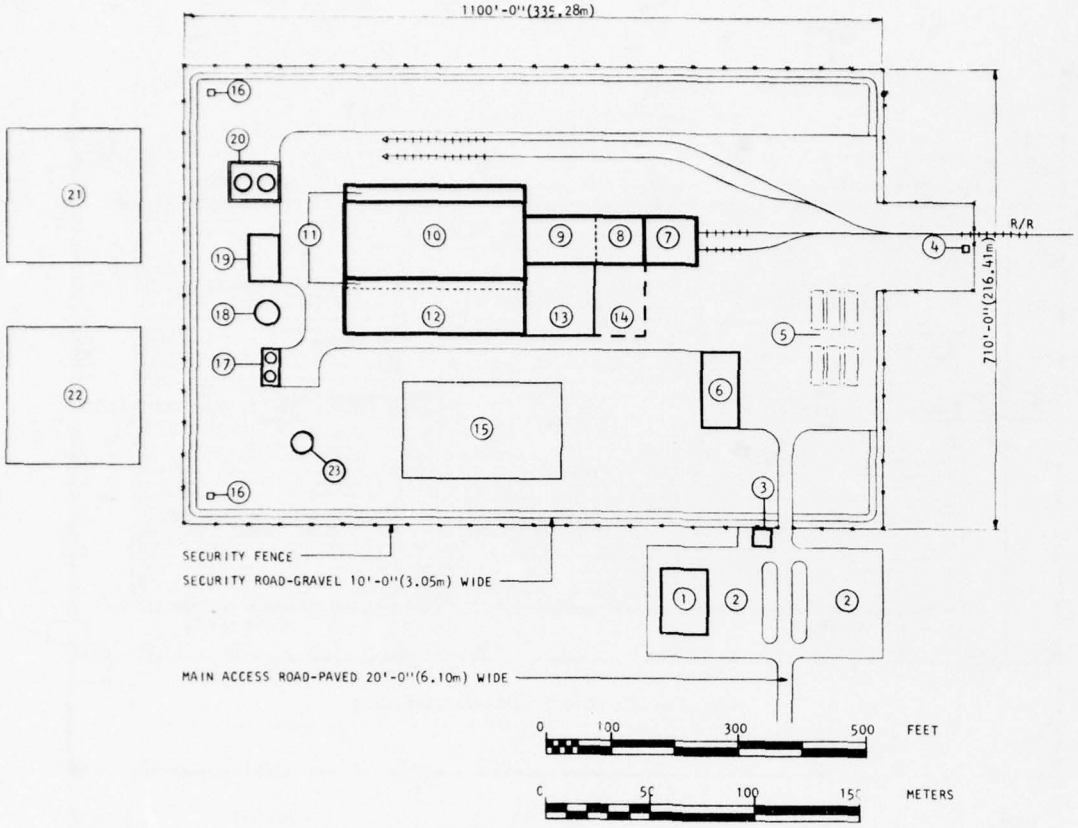


FIGURE 5.7.7. ISFSF, Plot Plan

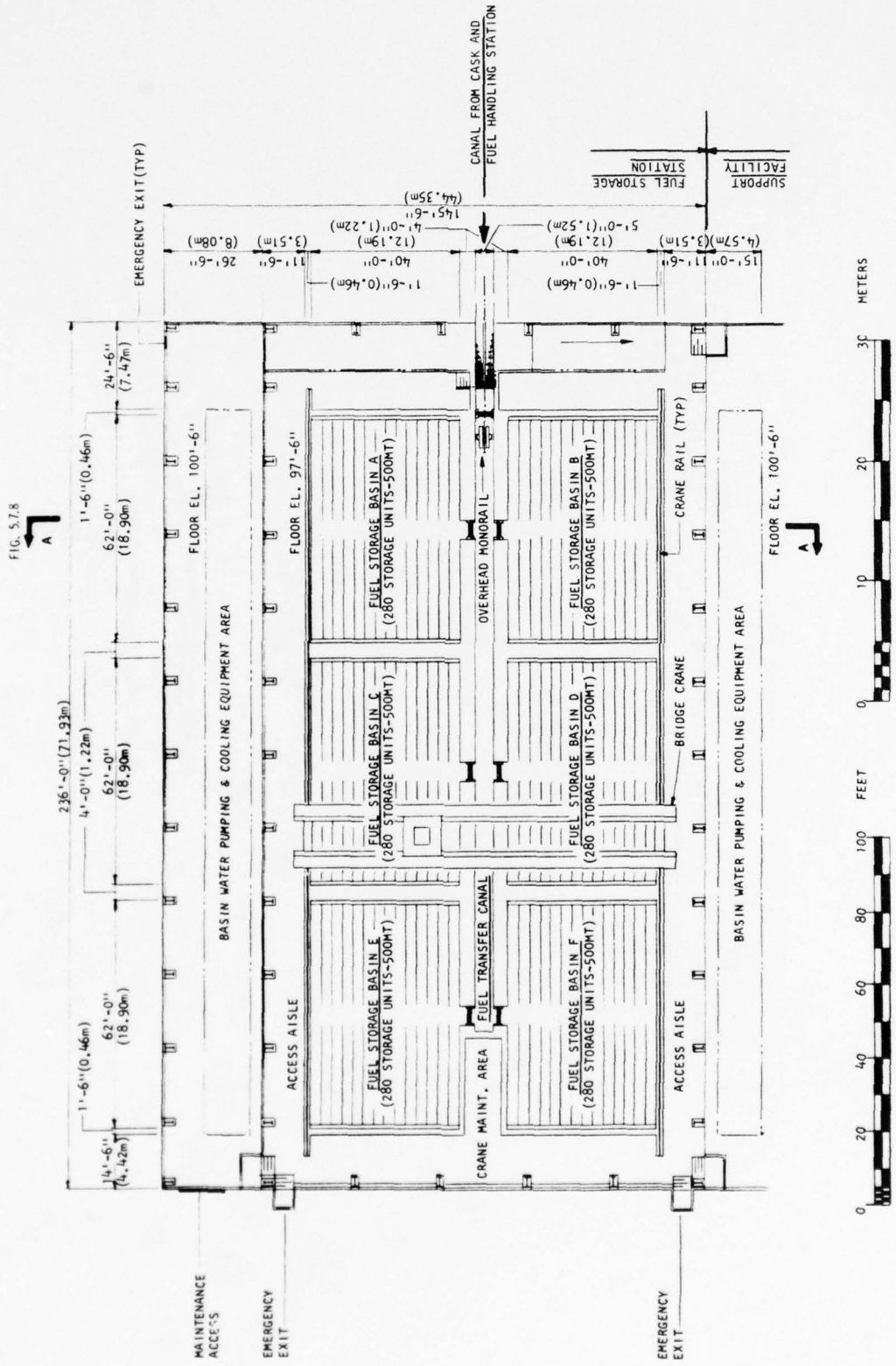


FIGURE 5.7.8. ISFSF, Plan View of Water Basin Storage Area

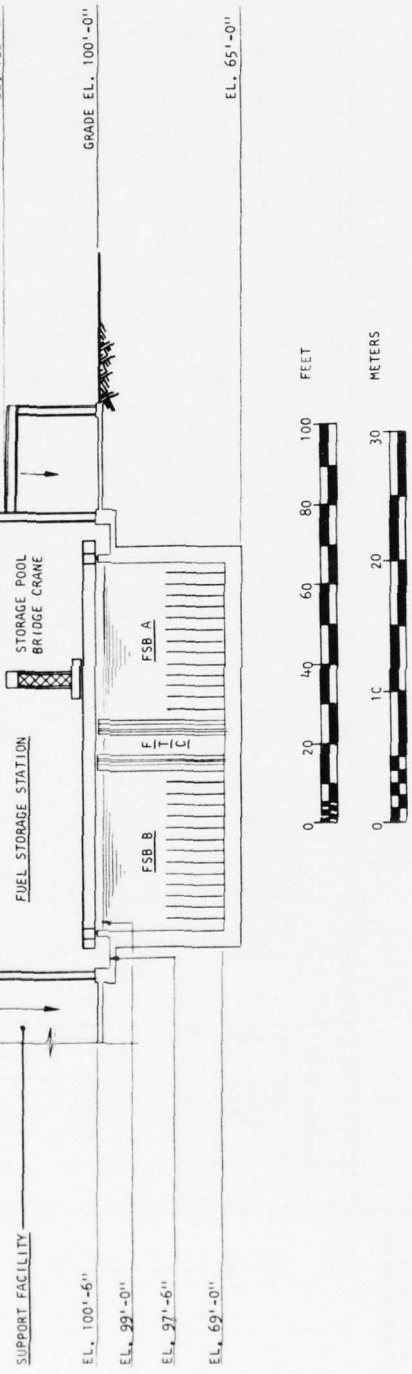


FIGURE 5.7.9. ISFSF Water Basin Storage Area, Section A-A

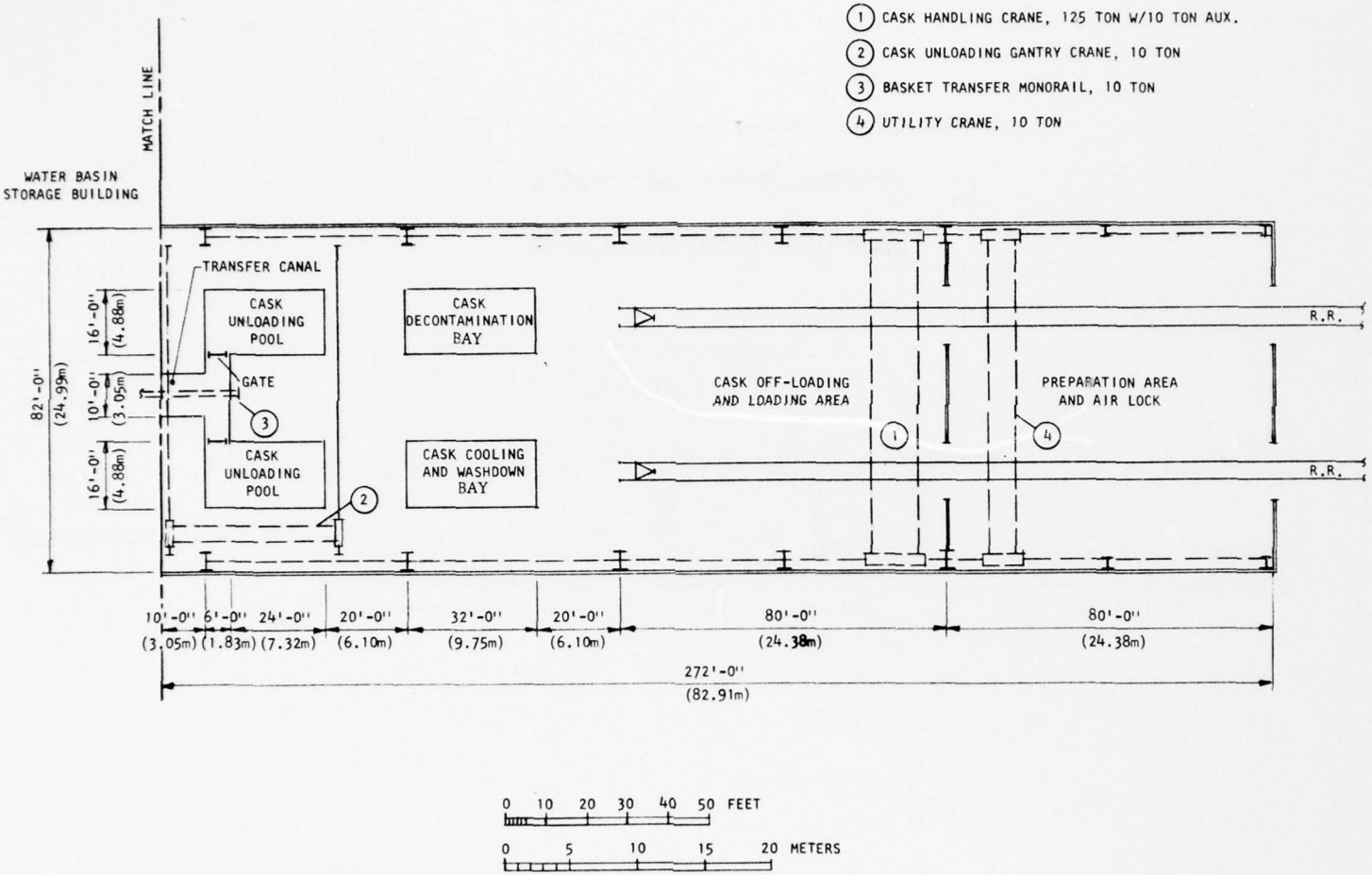


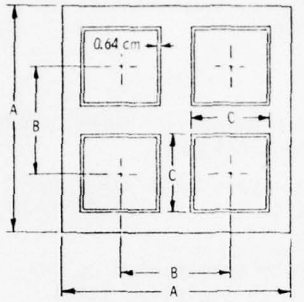
FIGURE 5.7.10. ISFSF, Receiving Area Plan

TABLE 5.7.6. Description of Fuel Storage Basins and Related Structures

Structural Item	Description	Category I
• Foundations	Reinforced concrete	As applicable
• Cask and fuel handling area		
Superstructure	Structural steel framing, including crane girders and support columns	yes
Roof deck and siding	Special insulated type, with "blow-away" feature designed to fail in the event of a tornado	yes
Cask unloading pools (CUPs)	Reinforced concrete constructed below-grade and lined with stainless steel	yes
Fuel transfer canals	Reinforced concrete constructed below grade and lined with stainless steel	yes
Wash and decontamination pits	Reinforced concrete constructed below grade and lined with stainless steel	no
• Fuel storage basin facilities		
Superstructure	Structural steel framing	yes
Roof deck and siding	Special insulated type, with "blow-away" feature designed to fail in the event of a tornado	yes
Fuel storage basin and transfer canals	Reinforced concrete lined with stainless steel and constructed to have the nominal water surface below grade	yes
Fuel storage baskets and racks	Stainless steel	yes
• Emergency power area		
Superstructure	Reinforced concrete	yes
• Radioactive waste and water treatment area		
Superstructure, including cells designed for shielding	Reinforced concrete	yes
• Support Facility Area		
Superstructure	Structural steel framing	no
Roof deck and siding	Insulated panels	no

the fuel storage baskets. The estimate assumes the use of stainless steel baskets that allow a 35.5 cm (14 in.) spacing of PWR assemblies containing up to 5.0% ^{235}U.* This spacing as well as spacing for BWR assemblies, requires verification during detailed

* Maximum ^{235}U content in unirradiated PWR assemblies is currently ~3.5%. The use of the 35.5 cm (14 in.) spacing required for 5 wt% ^{235}U provides an added degree of conservatism.



A = 71 cm MINIMUM
B = 35.5 cm
C = 24 cm
LENGTH = 457 cm
MATERIAL - STAINLESS STEEL

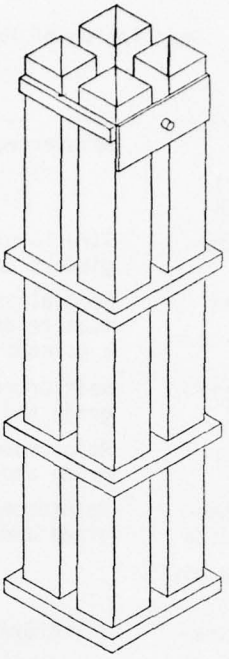
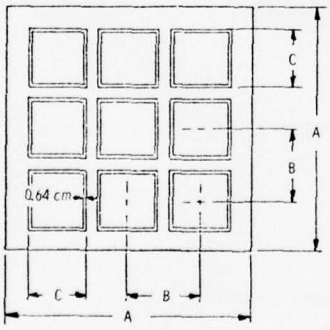


FIGURE 5.7.11. PWR Fuel Storage Basket



A = 71 cm MINIMUM
B = 24 cm
C = 16.5 cm
LENGTH = 457 cm
MATERIAL - STAINLESS STEEL

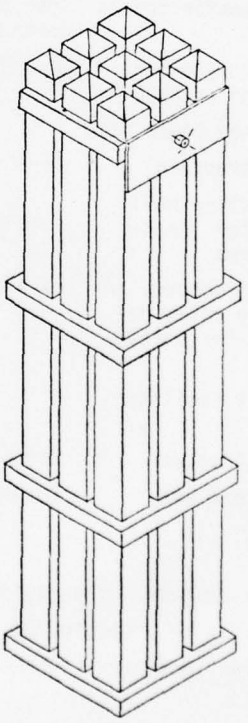


FIGURE 5.7.12. BWR Fuel Storage Basket

design. It is also assumed that nine BWR assemblies can be stored in the same space as four PWR assemblies. The General Electric spent fuel storage facility at Morris, IL, which uses stainless steel baskets, stores four PWR assemblies or nine BWR assemblies in essentially the same space. The storage facility at Barnwell, SC, (BFRSS) currently plans to use aluminum storage baskets and to store either eight PWR assemblies or 18 BWR assemblies in equivalent spaces.

Other major equipment and systems associated with the main fuel storage basin include:

- fuel basket handling and storage crane
- fuel storage racks to hold the baskets
- basin water cooling systems
- basin water cleanup and treatment systems
- criticality monitoring system.

Support Systems. Support systems at the site are defined as those ancillary to the water basin storage operations; these include:

- heating, ventilating and air conditioning (based on once-through design)
- cooling water systems (cooling towers and emergency basin water cooling pond)
- water supply, both process and emergency
- steam generation
- compressed air
- commercial and emergency electrical power supplies
- fire protection
- analytical laboratory
- administration and personnel service buildings and parking
- security, including gate house, yard fencing, lighting, and intrusion alarms
- personnel areas such as change rooms, lunch rooms, and health physics facilities
- roads and railroads
- cask-truck trailer parking
- rail siding for cask rail cars
- warehouse
- sanitary disposal system
- fuel oil storage
- equipment and instrument maintenance areas
- water evaporation pond
- chemicals make-up.

Facilities Not Included. The spent fuel shipping casks and transporters are not included within the scope of the reference storage facility and are described in Section 6.2.

Shielding and Remote Handling Equipment. The reference facility is designed for a combination of contact and semiremote operations using hand tools, cranes, and carts. Semiremote operations are performed underwater where they can be seen and controlled from above. The pool water and the shipping cask provide radiation shielding for the facility operators. The shielding is designed to keep the average dose rate to operating personnel below 1 mrem/hr.

5.7.1.5 Operating and Maintenance Requirements for the ISFSF

The facility is designed to operate 24 hr a day, 7 days a week, year round. The facility handles up to 1000 MTHM/yr; this may be 1000 MTHM/yr received, 1000 MTHM/yr shipped, or a combination of both receiving and shipping which totals 1000 MTHM/yr. Based on receiving 500 MTHM/yr and shipping 500 MTHM/yr and assuming 90% of the fuel is received in 4-MTHM casks, 10% is received in 0.4-MTHM truck casks, and all the fuel is shipped in a 4-MTHM rail cask, up to 113 rail casks and 125 truck casks are unloaded per year and 125 rail casks are shipped.

The average turn-around time for a cask is shown in Table 5.7.7. The average time to move a fuel basket (four PWR assemblies or nine BWR assemblies: 1.8 MTHM) into storage position is 1 hr. Based on handling two casks simultaneously the required spent fuel receiving and shipping could be accomplished in approximately 230 days per year.

TABLE 5.7.7. Time Cycle for Unloading a Spent Fuel Cask

Activity	Time, Hours GE IF-300 Cask(a,b)	NAC-1 (b)
Preparation	9	8
Radiation survey		
Handling		
Washdown		
Cooldown		
Loosening head bolts		
Unloading	12	4.2
Handling		
Head removal		
Fuel removal		
Head replacement		
Decontamination	8	1.9
Head bolt replacement		
Decontamination		
Handling		
Other activities	8	4.0
Radiation survey		
Handling		
Spot decontamination		
Delays		
Total	37	18.1

a. The turn-around time for an NLI-10/24 cask is about the same as that for the GE IF-300.
b. Casks are described in Section 6.2.

The facility is designed for contact operation and maintenance except for fuel handling facilities and equipment. Water-shielded facilities include the fuel unloading and storage basins and the transfer aisles. The only shielded area is the radioactive waste and basin water treatment facility, which includes equipment used for basin water cleanup (such as the filters, ion exchange columns, and the evaporator) and radioactive waste holding tanks. Because this equipment accumulates radioactivity from the basin water and any other waste solutions, it is generally flushed before maintenance to allow either contact or semiremote repairs or service. Spent fuel handling areas are maintained by using tools that can be operated underwater from a crane or by hand.

Personnel exposure is not normally a factor in the operation of this facility. During operation, personnel are normally excluded from the cells containing the basin water cleanup equipment. Normal exposure to operating personnel in the facility is less than 1 mrem/hr. During maintenance operations (e.g., servicing basin water cleanup equipment or equipment related to the fuel handling operations), loaded-cask handling, cleanup of fuel element leakage in the storage basin, and some equipment decontamination operations, personnel may receive radiation doses higher than normal; such doses, however, are controlled to well below the limits specified in Title 10, Part 20 of the Code of Federal Regulations.[8] Estimated radiation dose rates from loaded fuel casks during various stages of cask preparation are shown in Figures 5.7.13, 5.7.14, 5.7.15, and 5.7.16.

Facility operations and maintenance are performed using crane-mounted tools and hand tools. Bridge cranes or mobile cranes are used for moving equipment. Donkey engines and truck tractors are used for onsite cask carrier movement. Some special tools which are used to simplify maintenance operations and minimize exposure doses include extended tongs for work in the fuel basins and for remote connection on equipment contaminated with radioactivity.

If necessary, failed equipment is decontaminated by water flushing or other methods, drained of liquids, and may be wrapped or sprayed with plastic to fix residual contamination. Then, the failed equipment may be removed for repair or, if it cannot be repaired, it is packaged in a metal or wood box for movement to storage for transfer to a surface burial site.

Hazardous Materials. The only chemicals used in the storage process are nitric acid, caustic, and other decontaminating agents; these substances are handled according to safe industrial practices. Organic ion exchange resins are used for radionuclide cleanup of pool water and for cleaning a portion of the cask wash water. These resins are periodically replaced and do not present a safety hazard.

Staffing. Estimated staffing requirements for the facility for water basin storage of unpackaged spent fuel are shown in Table 5.7.8.

Supplies and Utilities. Table 5.7.9 shows the supplies used in facility operations. Table 5.7.10 lists the utilities required to operate the facility.

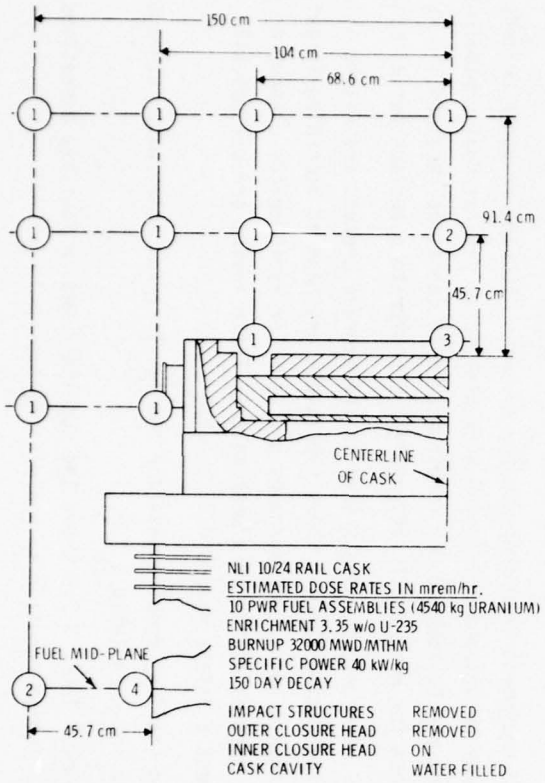


FIGURE 5.7.13. Estimated Dose Rates for the NLI 10/24 Rail Cask Water-Filled Cavity (Impact structures and outer closure head are removed. When these items are present, the dose rates are lower because of additional shielding.) Circled numbers are dose rates in mrem/hr.

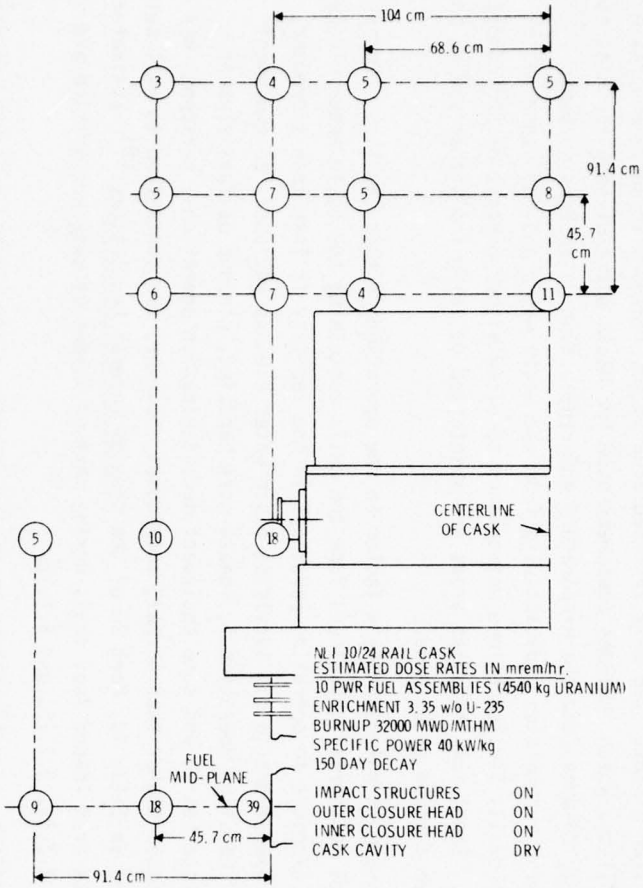


FIGURE 5.7.14. Estimated Dose Rates for the NLI 10/24 Rail Cask Dry Cavity (Cask is completely assembled.) Circled numbers are dose rates in mrem/hr.

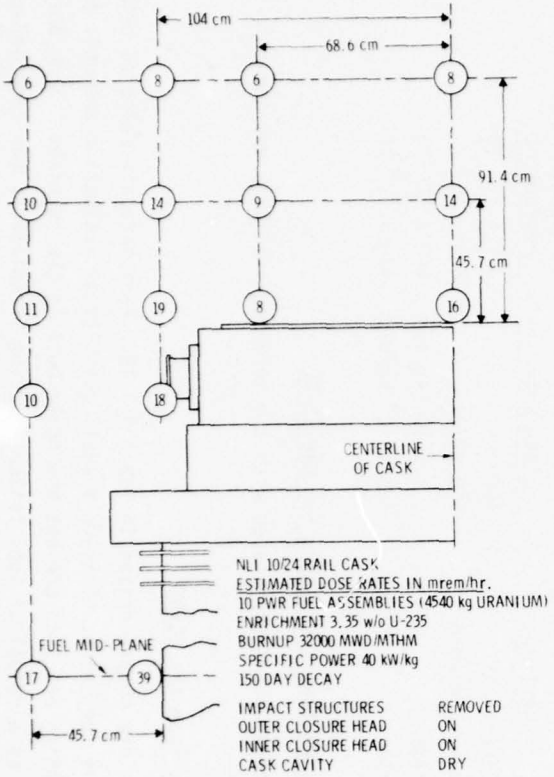


FIGURE 5.7.15. Estimated Dose Rates for the NLI 10/24 Rail Cask Dry Cavity (Impact structures removed.) Circled numbers are dose rates in mrem/hr.

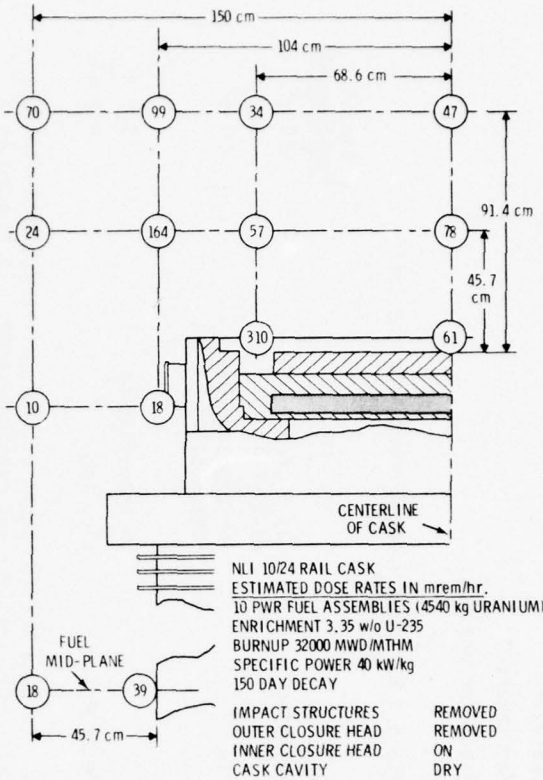


FIGURE 5.7.16. Estimated Dose Rates for the NLI 10/24 Rail Cask Dry Cavity (Impact structures and outer closure head removed.) Circled numbers are dose rates in mrem/hr.

TABLE 5.7.8. Staffing Requirements for the ISFSF

Job Description	Personnel Required, man-yr/yr
Operators	36
Maintenance	7
Radiation monitors	5

TABLE 5.7.9. Supply Requirements for the ISFSF

Material	Use	Annual Requirement
5% sodium hydroxide	Ion exchange bed regeneration	450 m^3
5% nitric acid	Ion exchange bed regeneration	300 m^3
Detergent		
SP-210[a]	Decontamination	3.8 m^3
Powdered detergent	Cleaning	0.2 m^3

a. SP-210 is a decontamination agent of a proprietary composition containing detergent, wetting, and rinsing agents. It is used as a 10 wt% solution in water. The decontamination solution has a pH of 10.9 and a specific gravity of 1.05.

TABLE 5.7.10. Utility Requirements for the ISFSF

Utility	Use Rate	Annual Requirement
Electricity	3000 kW	2.6×10^7 kWh
Water consumed	660 m^3/day	2.4×10^5 m^3
Steam	1.1×10^5 kg/day	4.0×10^7 kg
Coal	1.1×10^4 kg/day	4.0×10^6 kg

5.7.1.6 Secondary Radioactive Wastes for the ISFSF

Secondary radioactive wastes associated with the reference facility are shown in Table 5.7.11.

5.7.1.7 Emissions from the ISFSF

Facility emissions are characterized in Table 5.7.12. Radioactivity releases originate primarily from defective fuel rods, although a small quantity of activation products from spent fuel surface deposits are also present and contribute to the releases. Some defective fuel rods are expected as a result of fuel failures during irradiation, and some defects may develop during shipping and handling. In the relatively benign environment of water basin storage, the rod failure rate is expected to be so low in comparison that it can be ignored. A recent survey[1] of commercial nuclear fuel storage experience concluded that, "Neither chemical attack (corrosion) nor substantial mechanical damage have developed during pool

TABLE 5.7.11. Secondary Radioactive Wastes for the ISFSF

Description	Volume, m^3/yr	Radioactivity Factor[a] Activation Products	Fission Products
Combustible and compactable waste	650	All 7×10^{-3}	All 7×10^{-3}
Wet wastes	25	All 1.0	All 1.0
Failed equipment and noncombustible waste	70	All 6×10^{-4}	All 6×10^{-4}

a. Fraction of total secondary waste activity (column six of Table 3.3.4) in indicated waste category.

TABLE 5.7.12. Emissions from the ISFSF

Emissions	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere[a] Receiving[b]	Storage[c]
Gaseous	Facility and process air and vaporized excess water	Air 3.7×10^9 m^3	$^3H = 2 \times 10^{-6}$	1×10^{-6}
			$^{14}C = 3 \times 10^{-6}$	1×10^{-8}
			$^{85}Kr = 6 \times 10^{-5}$	7×10^{-7}
			$^{129}I = 1 \times 10^{-7}$	9×10^{-9}
			$Cs = 7 \times 10^{-11}$	9×10^{-12}
			Other FP $= 2 \times 10^{-12}$	2×10^{-13}
			Actinides = negligible	negligible
			Activition products $= 2 \times 10^{-10}$	2×10^{-11}
	Minor accident integrated annual release		Included above	Included above
Cooling tower water	Evaporated (T = 38°C)	2.0×10^8 kg		
	Drift (T = 38°C)	1.0×10^6 kg		
	Blowdown (T = 27°C)	3.5×10^7 kg		
Other	Heat	$\leq 1.3 \times 10^5$ MW-hr (4.5×10^{11} BTU)		

a. Fraction of input activity (Table 5.7.2) released to atmosphere. Apply these factors to the facility inventory obtained by multiplying the values in Table 5.7.2 by the number of MTHM received or in storage in a given year. Use 0.5 year age for receiving and 3.5 year age for storage. Includes DFs in process off-gas system and process concentrator where applicable. Release assumed to be uniform over the year.
b. Release results from damage during handling. Release assumed to occur shortly after damage.
c. Fraction of input activity released during each year of storage.

storage and handling of commercial fuel." The defects or failures that are present or that develop during handling are principally pin holes and small cracks.

The defect rate during fuel irradiation in a commercial nuclear power plant has been found to be 1×10^{-4}/yr per unit irradiated.[7] The majority of the fuel assemblies containing failed fuel rods or more severe defects are assumed to be encapsulated in special failed fuel

containers at the power plant and thus do not contribute to the releases at this facility. A portion of them are not encapsulated, either because they escape identification or because the radioactivity release rate is so small that they are easily handled in the pool facilities without encapsulation.

The defect rate during receiving and shipping operations is assumed to be 2×10^{-4} per unit received or shipped. This is believed to be a conservatively high defect rate estimate. A major share of these defects are assumed to develop during shipment; and the release of radioactive materials occurs at the receiving site; thus this section considers only the releases during receiving and storing operations. As with assemblies that defect during irradiation, most of these defects, including any severe ones, are encapsulated in failed fuel containers. Assemblies with minor defects are passed on to storage without encapsulation.

More specifically, the radionuclide releases in Table 5.7.12 were calculated based on the following estimates and assumptions:

For Spent Fuel Receiving

- Fuel rod defect rate = 2×10^{-4} per unit received.
- Each defect results in release from the rod of 100% of the gaseous fission products present in the fuel rod gap and plenum.
- The fractions of the gaseous fission products present in the gap and plenum are: 0.01 for ^{3}H, 0.03 for ^{14}C, 0.3 for ^{85}Kr, and 0.1 for ^{129}I.
- 100% of the ^{3}H and ^{85}Kr released from the rod is released to the atmosphere.
- 50% of the ^{14}C released from the rod is released to the atmosphere via the process off-gas system and 50% is absorbed in the pool water and ultimately sent to the waste evaporator, where 1% of that 50% is released to the atmosphere.
- 50% of the ^{129}I released from the rod is released to the process off-gas system (where a decontamination factor of 10^{3} is achieved) and 50% is absorbed in the pool water and ultimately sent to the waste evaporator, where 1% of that 50% is released to the atmosphere (assuming the evaporator bottoms are basic).
- The fractions of nongaseous fission products and activation products that are released from the rods were calculated by dividing the nuclide inventories in liquid and solid wastes produced during receiving operations (listed in Table 3.3.4) by the total activities present in spent fuel (Table 3.3.6 and 3.3.7 for activation products and Table 3.3.8 for fission products). These calculations were based on ^{60}Co, ^{137}Cs, and ^{90}Sr to represent activation products, cesium, and other fission products, respectively. Cesium was calculated separately from other nongaseous fission products because of its characteristically higher leachability.

- 70% of the nongaseous fission products and activation products that are released from the rods are dissolved (or suspended) in the pool water and ultimately sent to the waste evaporator, where 10^{-5} is released to the atmosphere with the vaporized excess water. The other 30% of these materials are removed in solid wastes (Table 3.3.25).

For Spent Fuel Storage

- The number of defected fuel rods exposed to the pool environment are 1×10^{-4} of the total number of rods (this is about 20% of the estimated total number of defected rods). All other defected assemblies are overpacked for storage and produce no further releases.
- The rate of release from the defected rods to the pool of the tritium, carbon, krypton, and iodine is 1% per year of that initially present in the bulk fuel.
- The ^{3}H and ^{85}Kr released from the rods is released to the atmosphere via the ventilation air.
- The ^{14}C and ^{129}I released from the rods is sent ultimately to the waste evaporator, where 1% is released.
- The release factors for nongaseous fission products and activation products were estimated using the same method as in the receiving case. In this case the reference quantities of nongaseous fission products were the Table 3.3.4 nuclide inventories in liquid and solid wastes produced during storage operations.

The only minor accident identified in Section 5.7.1.9 that results in a radioactivity release is a fuel handling accident where a pin hole leak develops in a fuel rod. This is the same type of incident that produces the defect during receiving and shipping discussed above. The integrated annual release from minor accidents is assumed to be included in the releases already described.

5.7.1.8 Decommissioning Considerations for the ISFSF

The storage facility is designed and constructed so that it has a useful operational life of 30 years. At the end of its operating life, the storage facility and associated equipment are expected to be contaminated with 100 Ci of mixed fission products. A decommissioning plan would be developed as part of the design. A quality assurance program covering all aspects of design, procurement, construction, and operation ensures that all design and operating requirements are met. Decontamination and decommissioning of the storage facility must be facilitated by providing appropriate decontamination equipment and systems and by incorporating monitoring and recording equipment to make an assessment of contamination levels. Materials and equipment for the facility are selected for their inherent ease of ultimate retirement and removal. Facility structure and equipment surfaces highly susceptible to significant radionuclide contamination that would be difficult to remove are covered with a removable surface.

5.7.1.9 Postulated Accidents for Water Basin Storage of Unpackaged Spent Fuel

Postulated minor, moderate, and severe accident scenarios for the reference facility are given in Tables 5.7.13, 5.7.14 and 5.7.15. Proper facility design, construction, and operation helps to prevent accidents, as does a quality assurance program that establishes and maintains the necessary integrity of the systems. Deviations that may occur are handled by protective features designed to place and hold the affected system in a safe condition.

TABLE 5.7.13. Minor Accidents for Water Basin Storage of Unpackaged Spent Fuel

Accident No. and Description	Sequence of Events	Safety System	Release
5.7.1 – Loss of normal electrical power; expected frequency 0.2/yr.	1. Power to substation supplying spent fuel receiving and storage facility interrupted. 2. Equipment motion stops. 3. Emergency power supplied to facility. 4. Operations resumed.	1. Automatic brakes activated by power loss. 2. Emergency diesel generator.	None
5.7.2 – Loss of normal cooling water supply; expected freqency 0.2/yr.	1. Cooling water supply stops because of power outage. 2. Emergency power supplied to cooling water pumps.	1. Emergency diesel generation.	None
5.7.3 – Reduction of normal cooling water supply; expected frequency 0.25/yr.	1. Pump or heat exchanger failure. 2. Temperature begins to slowly rise in pool. 3. Emergency cooling provided. 4. Pool temperature reduced to normal.	1. Pool temperature instrumentation. 2. Backup pumps are installed.	None
5.7.4 – Ventilation system failure; expected frequency 0.25/yr.	1. Failure of exhaust or supply fan motor. 2. Backup system automatically starts up.	1. Redundant ventilation exhaust and supply fans.	None
5.7.5 – Leak in water treatment system; expected frequency 0.025/yr.	1. Gasket fails, pool water leaks to floor. 2. Leakage enters sump and triggers an alarm. 3. Leakage returned to pool and leak repaired. 4. Spill area decontaminated.	1. Leak collection system and alarms.	None
5.7.6 – Minor fuel handling accident; expected frequency 3/yr.	1. One PWR fuel rod in a mishandled fuel assembly develops a pin hole leak. 2. Released gases travel to surface; particles are absorbed; 99% of ^{129}I and ^{14}C is absorbed. 3. Failed assembly is moved to the cask unloading pool and placed in a canister.	1. Operators trained for safe equipment operation. 2. Water containment traps fission products. 3. Redundant activity sensors and alarms detect leak. 4. Respiratory protection equipment available if needed. 5. Emergency ventilation exhaust treatment equipment available if needed. 6. Canisters are used to package failed assemblies.	Released through the plant stack over two days: $^{3}H = 8 \times 10^{-3}$ Ci $^{14}C = 4 \times 10^{-7}$ Ci $^{85}Kr = 5$ Ci $^{129}I = 6 \times 10^{-8}$ Ci All others negligible

TABLE 5.7.14. Moderate Accidents for Water Basin Storage of Unpackaged Spent Fuel

Accident No. and Description	Sequence of Events	Safety System	Release
5.7.7 – Fuel handling accident; expected frequency 0.7/yr.	1. 1% of fuel rods severly ruptured in a PWR assembly due to rough handling and impact. 2. Released gases travel to surface; particles are absorbed; ^{129}I and ^{14}C are partially absorbed (99%). 3. Gaseous activity causes the ventilation air to be diverted through off-gas system. 4. Workers don respiratory protection. 5. Failed element is moved to the cask unloading pool and placed in a canister. 6. Flow to filter-deionizer system is increased for rapid pool cleanup.	1. Operators trained for safe equipment operation. 2. Water containment traps fission products. 3. Redundant activity sensors, alarms, and automatic ventilation diversion equipment. 4. Off-gas system equipped to capture iodine and particles. 5. Canisters for packing failed elements are available.	In a 15 min period the following are released via the plant stack: $^{3}H = 2 \times 10^{-2}$ Ci $^{14}C = 1 \times 10^{-6}$ Ci $^{85}Kr = 13$ Ci $^{129}I = 1.5 \times 10^{-10}$ Ci All others negligible
5.7.8 – Fuel handling accident without confinement protection; expected frequency 5×10^{-4}/yr.	1. Sequence of events same as in Accident 5.7.7 except the off-gas is not diverted through a filter system.	1. See Accident 5.7.7.	In a 15 min period the following are released via the plant stack: $^{3}H = 2 \times 10^{-2}$ Ci $^{14}C = 1 \times 10^{-6}$ Ci $^{85}Kr = 13$ Ci $^{129}I = 1.5 \times 10^{-7}$ Ci All others negligible
5.7.9 – Rail cask venting; expected frequency 4×10^{-5}/yr.	1. Accidental venting of 4.6 MTHM rail cask with 0.04% failed fuel (one PWR rod) to the facility because of improper placement of off-gas equipment. 2. Personnel evacuated. 3. Ventilation exhaust automatically diverted to emergency off-gas system. 4. Release exits facility via the stack.	1. Redundant activity sensors and alarms detect release. 2. Emergency ventilation exhaust treatment equipment for I and particulate removal.	Gaseous release via the plant stack during a 15 min. period are: $^{3}H = 8 \times 10^{-3}$ Ci $^{14}C = 4 \times 10^{-5}$ Ci $^{85}Kr = 5$ Ci $^{129}I = 6 \times 10^{-9}$ Ci All others negligible
5.7.10 – Shipping cask dropped into cask unloading pool.	1. Equipment failure or operator error causes cask to drop into cask unloading pool. 2. Shipping cask inspected for damage. Cask expected to be undamaged. 3. Impact absorber removed and repaired if damaged.	1. Impact absorber minimizes cask damage.	None

TABLE 5.7.14 (contd)

Accident No. and Description	Sequence of Events	Safety System	Release
5.7.11 – Dropped fuel transfer basket; expected frequency 0.07/yr.	1. Crane failure or operator error causes drop of fuel basket. 2. Due to impact, pin hole leaks develop in 4 separate rods. 3. See sequence of events 2 through 6 in accident 5.7.7.	1. Basket height kept close to pool bottom. 2. Basket protects fuel cladding. 3. Baskets also protect fuel already in storage. 4. See safety systems 1-5 of accident 5.7.7.	Gaseous release out the plant stack during a 15 min. period are: ^{3}H = 3.2×10^{-2} Ci ^{14}C = 1.6×10^{-6} Ci ^{85}Kr = 20 Ci ^{129}I = 2.4×10^{-10} Ci All others negligible

TABLE 5.7.15. Severe Accidents for Water Basin Storage of Unpackaged Spent Fuel

Accident No. and Description	Sequence of Events	Safety System	Release
5.7.12 – Design basis tornado; expected frequency 1×10^{-5}/yr.	1. Tornado strikes facility. 2. During the single pass, the roof fails, exposing the pool water. 3. Some basin water is entrained by the tornado and transported offsite.	1. Building roof designed to "blow away" in a tornado to prevent structural damage. 2. Radioactive radwaste systems are tornado-proof so are undamaged.	16.5 MT of water are assumed entrained, which release instantaneously at ground level: 3.3×10^{-3} Ci of mixed fission products (78% ^{137}Cs, 12% ^{134}Cs, 1% ^{90}Sr, 5% ^{60}Co, 4% ^{55}Fe).
5.7.13 – Criticality; expected frequency 1×10^{-5}/yr.	1. Nuclear excursion at bottom of pool as a result of storage array disruption or mishandling (10^{18} fissions). 2. All cladding ruptures, on 4 PWR assemblies, releasing fission products. particles are retained in basin water and 99% of ^{129}I and ^{14}C are absorbed. 3. Emergency off-gas system is activated. 4. Accident terminated by relocation of assemblies. 5. Recovery would follow steps 3 through 5 of accident 5.7.7.	1. Fuel in undamaged racks is always subcritical. 2. Administrative controls and limited handling equipment prevent fuel accumulation outside of the storage racks. 3. Redundant activity alarms and sensors detect criticality. 4. Emergency ventilation exhaust treatment equipment. 5. Canisters are used to package failed assemblies.	Released through the plant stack over a 15 min period: ^{3}H = 7.9 Ci ^{14}C = 4.1×10^{-4} Ci ^{85}Kr = 5.2×10^{3} Ci ^{129}I = 5.9×10^{-8} Ci ^{131}I = 1.5×10^{-6} Ci ^{133}I = 1.1×10^{-4} Ci ^{134}I = 2.0×10^{-3} Ci ^{135}I = 4.8×10^{-4} Ci ^{83}Br = 8.6×10^{-5} Ci $^{84m+84}Br$ = 1.2×10^{-3} All others negligible
5.7.14 – Loss of cooling water supply.	1. Cooling towers become inoperative due to damage or mechanical failure. 2. Emergency cooling water supplied to heat exchanger before any fuel assemblies are damaged.	1. Cooling pond with highly reliable pumps and piping is available for emergency cooling. 2. Heat exchanger equipment is highly reliable (design redundancies).	None

Although accidents have occurred in spent fuel receiving and storage facilities, a review and analysis of incidents occurring in government and commercial nuclear facilities encompassing something over 100,000 reports indicates no instance of injury to a member of the general public.[5]

For purposes of environmental consequence analysis, the material releases associated with accident numbers 5.7.6, 5.7.12 and 5.7.13 in Tables 5.7.13 and 5.7.15 have been selected as umbrella source terms. (The concept of an umbrella source term is explained in Section 3.7.) This means that the releases from these accidents are the largest in their respective source term categories. The environmental consequences of these accidents are described in DOE/ET-0029.

Accidents are cross indexed with their appropriate umbrella source terms in Appendix A, Section 3.

5.7.1.10. Costs for Water Basin Storage of Unpackaged Spent Fuel

Estimates have been made, in mid-year 1976 dollars, of capital, operating and levelized unit costs. A description of the cost estimate bases, assumptions and definitions is given in Section 3.8.

Capital Costs. The total capital cost, presented in Table 5.7.16, includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation, with the exception of working capital.

TABLE 5.7.16. Capital Cost Estimate for the ISFSF

	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		130	31,000	1,500	32,500
Buildings and structures		1,750	12,700	21,000	33,700
Bulk materials		960	9,500	11,600	21,100
Site improvements		120	800	1,400	2,200
Subtotal of direct site construction costs		2,960	54,000	35,500	89,500
Indirect site construction costs	780	590	13,000	17,200	30,200
Total field cost	780	3,550	67,000	52,700	119,700
Architect-engineer services					23,900
Subtotal					143,600
Waste treatment facility					14,000
Owner's cost					42,400
Total facility cost					200,000
Estimate accuracy range					±30%

Note: The costs for PWR and BWR storage baskets all fabricated from stainless steel are included in the facility cost estimates. Costs are based on procurement in lots of 100 or more. The estimated unit costs for these items are:

PWR storage baskets - $9,000. BWR storage baskets - $14,000.

Operating Costs. The operating cost components for water basin storage of unpackaged spent fuel are shown in Table 5.7.17. Direct labor costs are based on manpower estimates given in Table 5.7.8. Process material costs are negligible. Utility costs are derived from requirements shown in Table 5.7.9. Annual maintenance materials costs are estimated at 3% of initial major equipment costs. Overhead and miscellaneous costs are estimated using the standard method described in Section 3.8. All costs are based on an annual receiving and shipping rate of 500 MTHM of spent fuel with 3000 MTHM stored in the basin. During the postulated 6-year startup and final inventory removal periods, operating costs are reduced to $3.4 million per year. If the water basin is operated in a simple storage mode with no receiving or shipping, annual operating costs are estimated to be $2.5 million. The estimates for the miscellaneous items are intended to include all unidentified operating costs. The costs of taxes, insurance, and interest are included in the capital charge segment of the levelized unit cost.

TABLE 5.7.17. Operating Cost Estimate for the ISFSF

Cost Element	Annual Costs, $1000s
Direct labor	700
Process materials	0
Utilities	700
Maintenance materials	1000
Overhead	1400
Miscellaneous	500
Total	4300
Estimate accuracy range	+50% -25%

Levelized Unit Costs. The levelized unit cost, including levelized capital and operating costs, is shown in Table 5.7.18 for two modes of operation: 1) a lag storage mode where spent fuel is held for radioactive decay and then shipped out, and 2) an extended storage mode where the basin is filled once and held. Costs of each mode are estimated for both private and Federal ownership.

TABLE 5.7.18. Levelized Unit Cost Estimate for the ISFSF

	Unit Cost, $/kg HM			
	6-Year Lag Storage Mode		Extended Storage Mode	
Cost Element	Private	Federal	Private	Federal
Levelized capital charge	104.10	47.30	168.60	84.50
Levelized operating charge	9.20	10.00	13.20	15.50
Levelized total unit cost	113.30	57.30	181.80	100.00
Estimate accurancy range	±35%	±35%	±30%	±30%

The lag storage mode of operation assumes a 90% capacity operation for the facility. Four hundred fifty metric tons of fuel are received annually for 16 years. After the first 6 years the basin is assumed to have reached its operating capacity of 2700 MTHM (the remaining 300 MTHM of capacity is used for surge storage). At this time, the oldest fuel has cooled 6 years; beginning in the seventh year, spent fuel is sent to be packaged at a rate of 450 MTHM per year. No spent fuel is received after year sixteen and the basin inventory is drawn down over the following 6-year period. The facility is then decommissioned at a cost of 10% of the initial capital cost.

The extended storage mode of operation assumes an annual receipt of 500 MTHM annually for the first 6 years until the basin is fully loaded. The basin then holds the fuel for 10 years; following this holding period the fuel is shipped out over a 6-year period, after which the facility is decommissioned.

The use of this concept for an extended storage application is shown to be an expensive operation. The facility was not designed for this application and the receiving and shipping facilities are inefficiently used. Costs for extended storage of unpackaged spent fuel could be reduced substantially by designing a facility that could be expanded to larger capacities in modular increments as in the case of water basin storage of packaged spent fuel described in Section 5.7.5.

A preliminary estimate for extended storage in a facility with capability of modular expansion was prepared for comparison purposes. The initial facility was assumed to be a 3000 MTHM basin with 2000 MTHM/yr receiving capability, as described in Section 5.7.2. Costs for additional 1000 MTHM or 2000 MTHM storage modules were based on incremental basin capacity costs described in Section 5.7.5.10. Spent fuel was received at a rate of 700 MTHM and 1300 MTHM per year respectively in the first two years, followed by nine years at 2000 MTHM/yr for storing a total of 20,000 MTHM. Following the last year of receiving, the spent fuel was shipped out at the rate of 2000 MTHM/yr. The levelized unit costs for this case were calculated to be $61 and $37/kgHM for private and Federal government ownership, respectively.

The higher unit cost for private versus government ownership shown in the unit cost table is the result of the higher cost of capital and payment of taxes. The unit costs for private ownership are approximately twice those estimated for Federal ownership.

5.7.1.11 Construction Requirements for the ISFSF

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating this impact.

Project Schedules and Construction Manpower. The estimated schedule for engineering, procurement, and construction of the storage facility is shown in Figure 5.7.17; Figure 5.7.18 gives data concerning the construction labor force.

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the storage facility, while offsite costs are

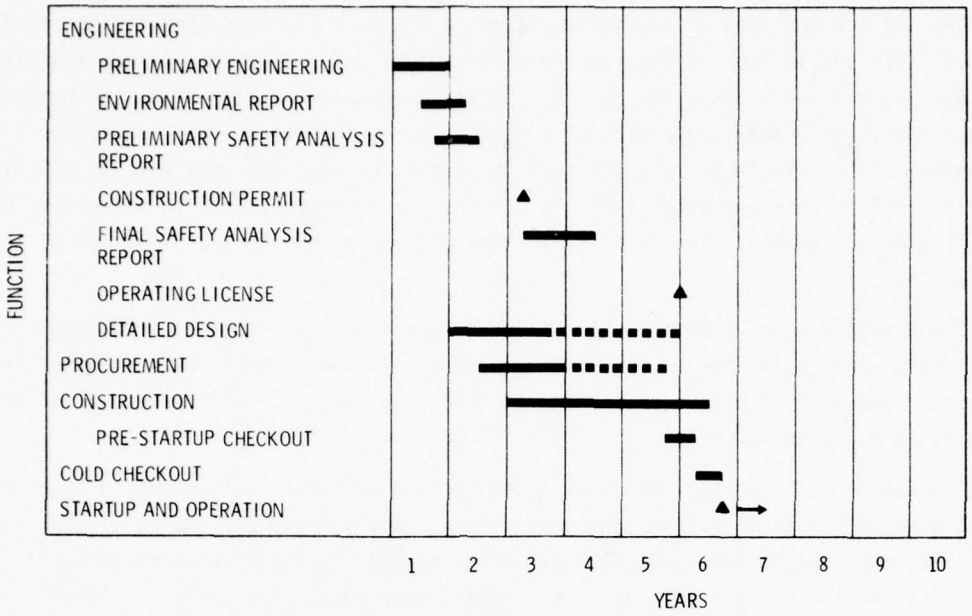


FIGURE 5.7.17. Engineering Procurement and Construction Schedule for the Facility for Water Basin Storage of Unpackaged Spent Fuel

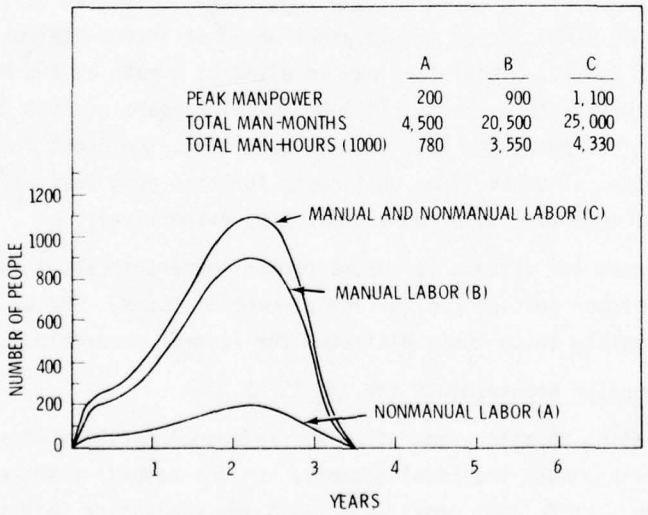


FIGURE 5.7.18. Construction Labor Force Schedule for the Facility for Water Basin Storage of Unpackaged Spent Fuel

those for all services provided, materials purchased, and equipment fabricated or assembled elsewhere. The distribution of total costs in these categories is shown below:

	Costs, $1000s
Onsite costs	65,000
Offsite costs	135,000
Total	200,000

Site Requirements. The major restriction on siting is that the reference facility not be located in a flood plain. Requirements for the facility location include:

- access to supply of water,
- access to rail and highway,
- access to moderate supply of electrical power, and
- minimum conflict with other beneficial land uses.

In general, the reference facility location conforms to the requirements of Title 10, Part 100, of the Code of Federal Regulations.[9] The facility requires a site of about 405 ha (1000 acres); approximately 10 ha (25 acres) within that site are required to be cleared for facility installations. An additional 4 ha (10 acres) must be cleared for construction storage, work yards, temporary buildings, and labor parking.

Water. About 53,000 m^3 (14 x 10^6 gal) of water are required during construction.

Construction Materials. Major material requirements for facility construction are:

Concrete	19,000 m^3	(25,000 yd^3)
Steel	9,100 MT	(10,000 tons)
Copper	27 MT	(30 tons)
Zinc	45 MT	(50 tons)
Lumber	1,100 m^3	(460 MBFM)

Energy. Energy resources used during construction are:

Propane	490 m^3	(130,000 gal)
Diesel fuel	4,900 m^3	(1,300,000 gal)
Gasoline	3,400 m^3	(900,000 gal)
Electricity		
Peak demand		1,300 kW
Total consumption		2,500,000 kWh

Transportation Requirements. Approximately 1.6 km (1 mile) of new road are required to provide automobile and truck access from the nearest U.S. highway to the site. Approximately 3.2 km (2 miles) of new railroad spur are required for site railroad service.

5.7.1.12 Effects on Fuel Cycle Options for the ISFSF

The following fuel cycle options have been evaluated relative to their influence on water basin storage of unpackaged spent fuel.

Once-Through Cycle. The application of water basin storage in the once-through cycle would depend on the timing and availability of facilities for long-term storage or disposal. If the technology has not been demonstrated or facilities are not available for long-term storage or isolation, water basin fuel storage could provide interim fuel storage. Water basin storage facilities at independent sites could be used until the fuel is disposed of, reprocessed, or stored in a more permanent manner.

Uranium-Only Recycle. With uranium recycle, water basin storage of unpackaged fuels could be used until capability is available to reprocess the fuels. Water basin storage facilities at independent sites might provide an economical method for utilities to store spent fuels once their onsite fuel storage capacity is full.

Uranium and Plutonium Recycle. The application of water basin storage with uranium and plutonium recycle would be the same as for uranium-only recycle.

5.7.2 Modified Independent Spent Fuel Storage Facility

Because a spent fuel packaging facility requires spent fuel receiving capabilities as well as some storage capability similar to that provided at an ISFSF, it is logical to combine a packaging facility with an ISFSF. For this purpose the ISFSF described in Section 5.7.1 has been modified to receive spent fuel at a higher rate and route it to a fuel packaging facility. The modified facility described here has double the capacity, 2000 MTHM/yr, to receive and/or ship spent fuel. A water transfer canal system is provided to route fuel within the modified storage facility to the adjacent fuel packaging facility (FPF) and an additional 50-MTHM surge storage pool is provided. The fuel storage functions and the operations and technology employed for the modified storage facility are the same as for the preceding water basin storage facility.

5.7.2.1 Alternatives for the Modified ISFSF

The alternatives for the modified water basin storage of unpackaged spent fuel are the same as those discussed in Section 5.7.1.1.

5.7.2.2 Design Basis for the Modified ISFSF

The assumptions made in the design of the facility for modified water basin storage of unpackaged fuel are the same as those discussed in Section 5.7.1.2 with the following exceptions:

- The facility has the capability to receive 2000 MTHM/yr, or handle ∿6.7 MTHM/day for 300 days/yr.
- Of the fuel received, 1800 MTHM/yr are delivered in rail casks and 200 MTHM/yr are delivered in truck casks.
- Spent fuel cooled 6.5 years after discharge from a reactor can be routed to an adjacent packaging facility.
- Approximately 500 MTHM of the fuel received each year have been cooled for only 6 months. Such fuel is stored in the reference facility for 6 years, after which it is sent to the fuel packaging facility (FPF). The balance of the fuel received at this reference facility has been cooled elsewhere for 6.5 years; on receipt, this fuel is routed directly to the FPF.
- A 50-MTHM short-term surge storage pool is provided for continuity of operations between the modified storage facility and the FPF. In addition, up to 300 MTHM of the main storage capacity is allocated to longer-term surge storage.
- Additional heat dissipation capacity (∿50 kW) and water cleanup capability are needed to service the added water transfer canals and the surge storage pool.

5.7.2.3 Operations for the Modified ISFSF

The majority of facility operations are the same as those for the previously described facility for water basin storage of unpackaged spent fuel (Section 5.7.1.3). The additional operations performed in the modified facility include transfer of fuel from the fuel receiving

area and the storage pools, to the FPF. These operations are shown in Figure 5.7.19. Overall operations at the facility for modified water basin storage are summarized as follows:

- Casks are received, and the spent fuel is unloaded into baskets in the cask unloading pool (CUP).
- The loaded baskets are moved by an overhead monorail to either the main fuel storage area or to the fuel transfer canal where they are placed on an underwater cart and moved to the 50 MTHM surge storage area.
- If delivered to the main storage area, the baskets are moved by a bridge crane to a storage location.
- If delivered to the surge storage transfer canal the loaded baskets are then either transferred by bridge crane to a surge storage rack before subsequent delivery to the FPF or immediately transferred to the FPF via the bridge crane and a transfer canal cart.

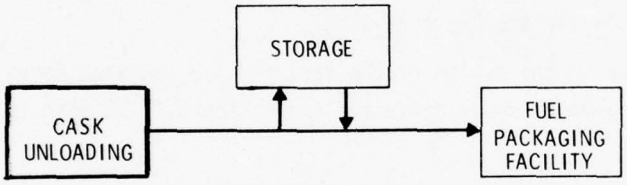


FIGURE 5.7.19. Facility Operations for the Modified ISFSF

5.7.2.4 Description of the Modified ISFSF

Figure 5.7.20 is a layout of the facility for the modified ISFSF. The modified facility requires approximately the same plant area as the unmodified version (see Section 5.7.1.4), however, the facilities are rearranged to provide for three cask unloading stations and increased space for yard parking of up to 10 rail casks and 10 truck casks and for tie-ins to the adjacent onsite spent fuel packaging facility. Plan and section views of the water basin for this facility are shown on Figures 5.7.21 and 5.7.22. Figure 5.7.23 shows a plan view of the receiving area.

The main plant includes the cask and fuel handling area, the storage basins, and the radioactive waste and water treatment area. A 50-MTHM surge pool and transfer canals are added as a tie-in to the packaging facility. Support, utility, and service facilities are also provided as part of the reference facility. The structural features of the various facilities are summarized in Table 5.7.6 of Section 5.7.1.4; items that must meet Category I standards are so indicated.

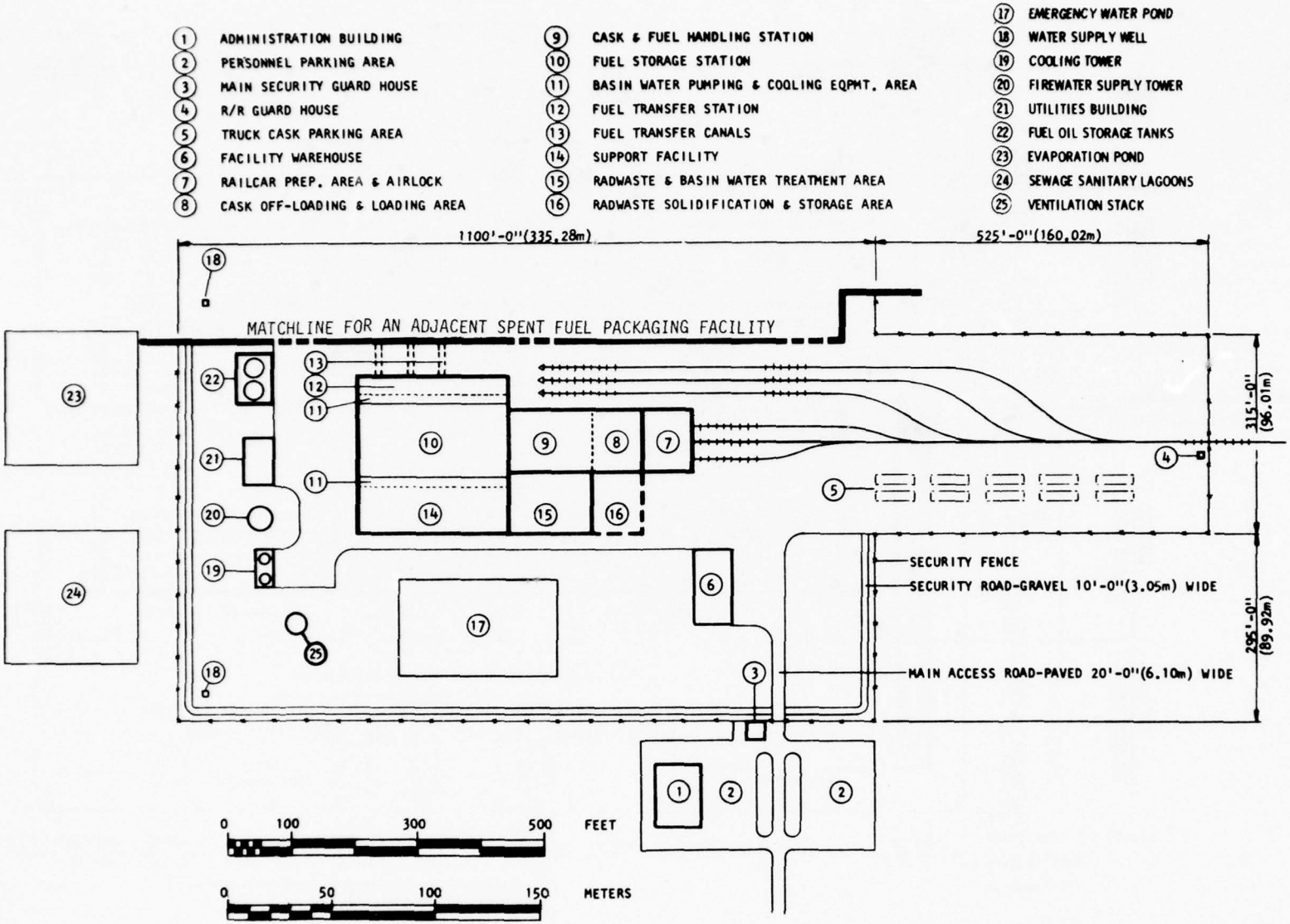


FIGURE 5.7.20. Plot Plan for the Modified ISFSF

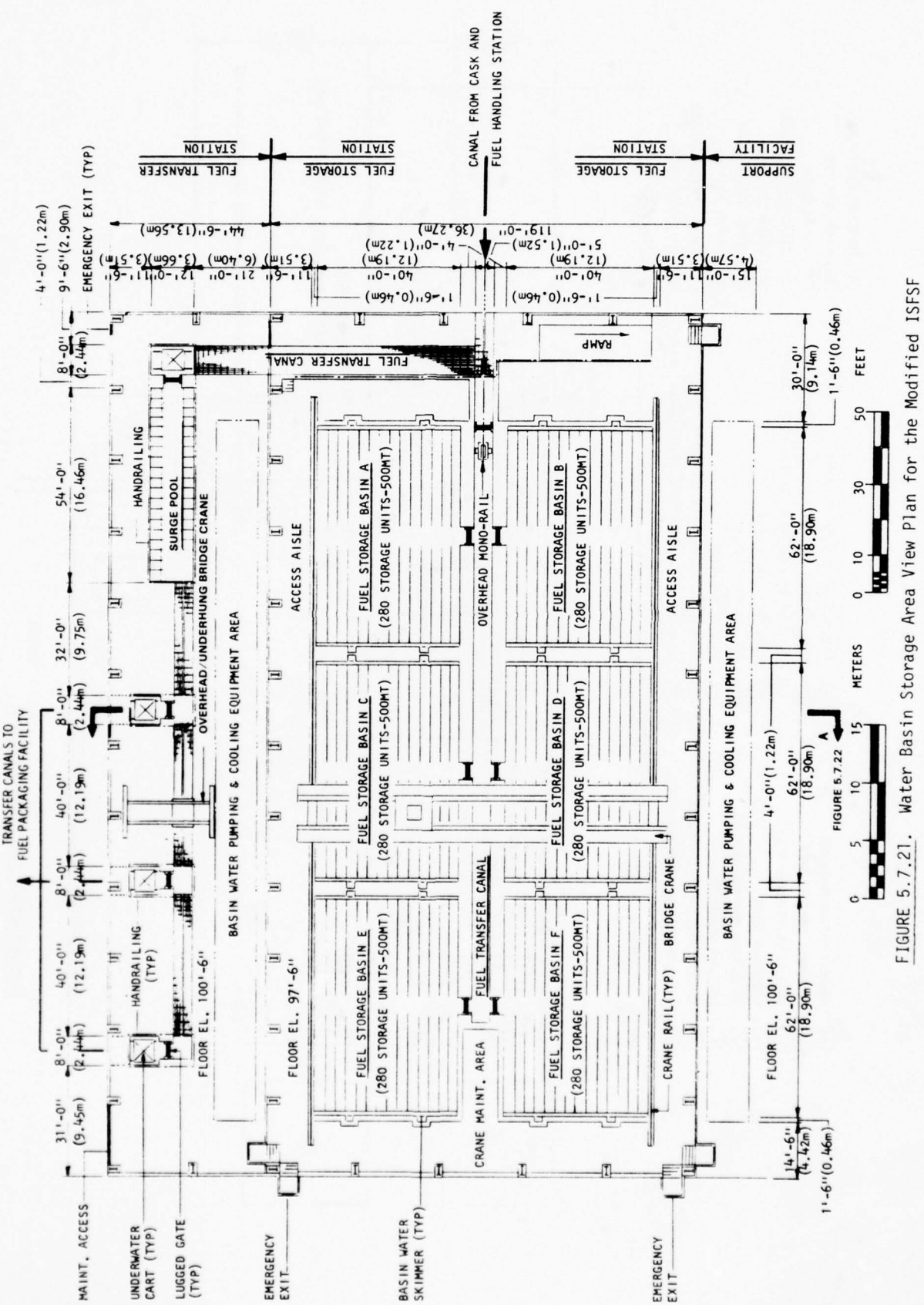


FIGURE 5.7.21. Water Basin Storage Area View Plan for the Modified ISFSF

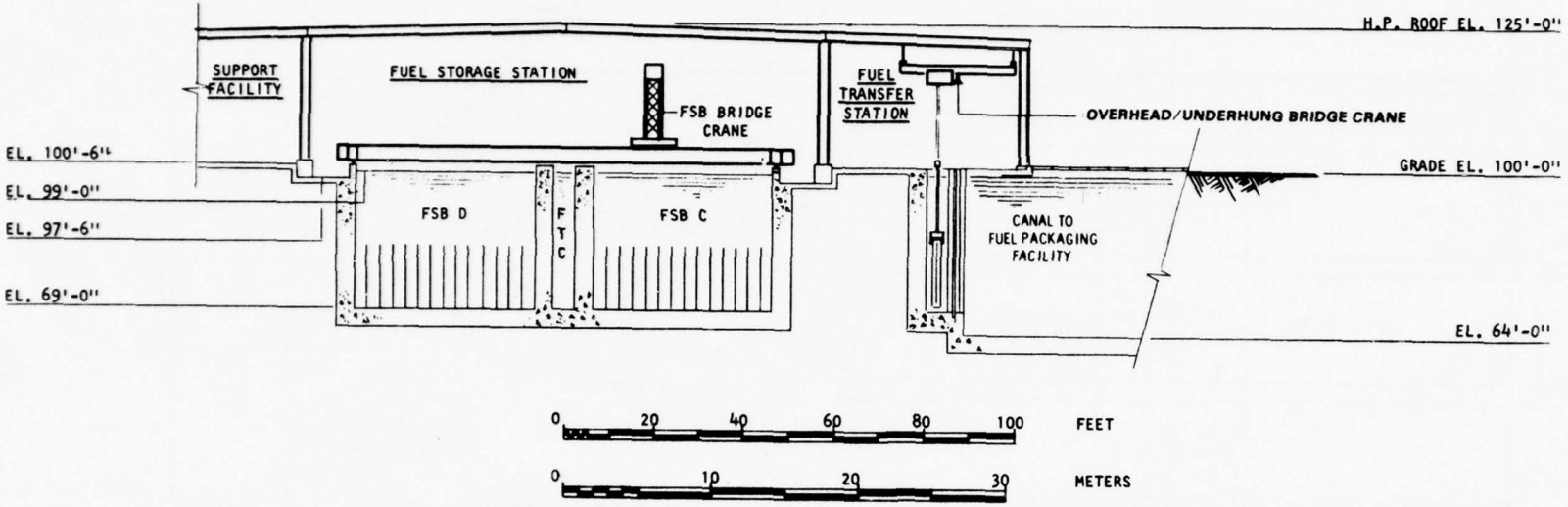


FIGURE 5.7.22. Modified ISFSF, Section A-A

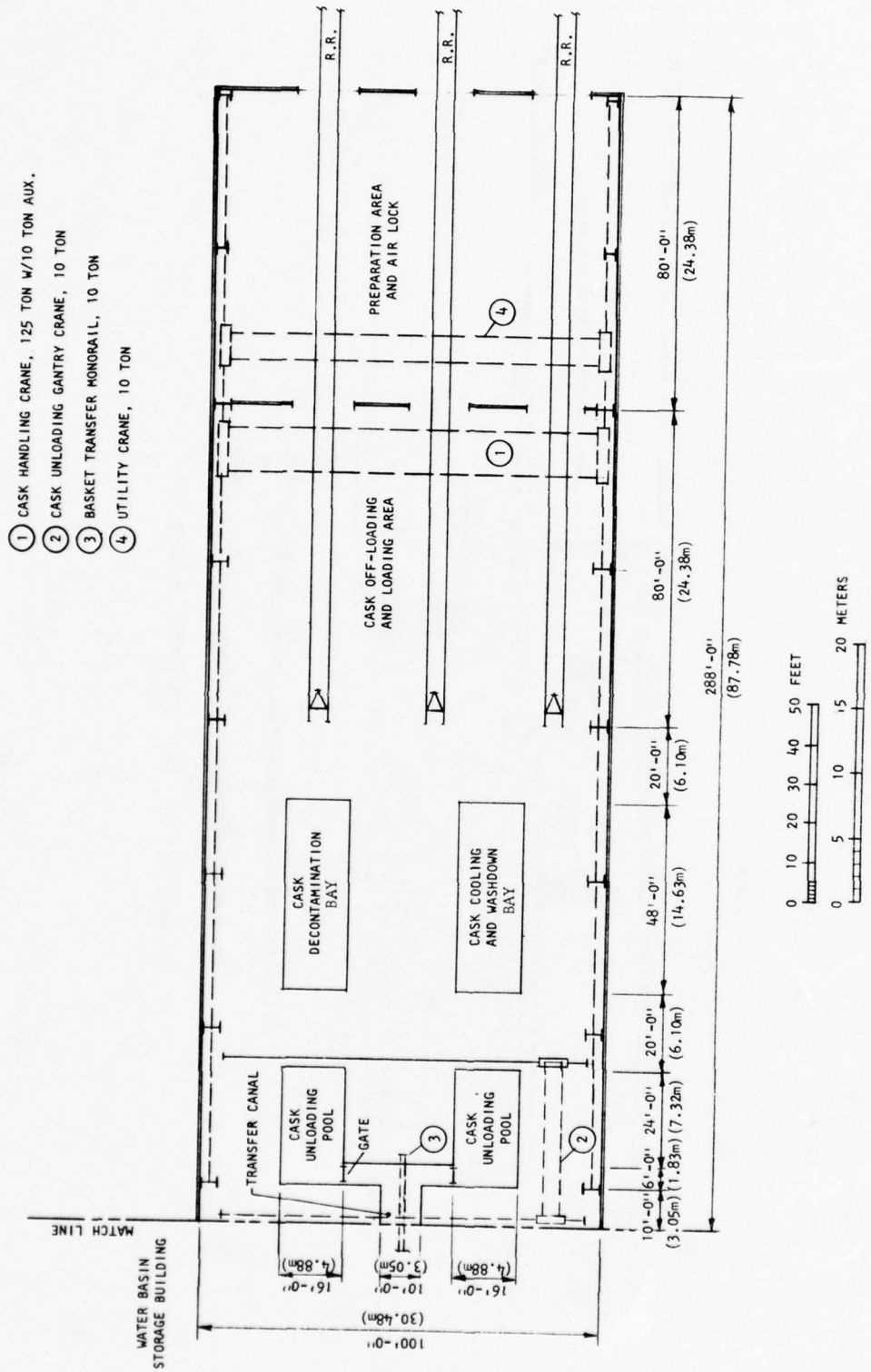


FIGURE 5.7.23. Cask and Fuel Handling Facility Plan for the Modified ISFSF

Cask and Fuel Handling Systems. The cask and fuel handling systems for the modified facility are the same as those described in Section 5.7.1.4 with one exception; a three-rail cask unloading station is provided, with three parallel bays for cask preparation and for cask removal and loading either from rail cars or truck-trailers. The cask and fuel handling system has a capacity of 2,000 MTHM/yr.

Fuel Storage Basin Systems. The main fuel storage basin (FSB) consists of six near-surface, water-filled pools of heavily reinforced concrete. These pools are lined with stainless steel and have auxiliary equipment to cool and control the quality of the water. Each individual pool has a storage capacity of 500 MTHM. Gates permit isolation of each pool area. The FSB has approximately 1,365 m^2 (14,700 ft^2) of pool water surface (not including transfer canals) and a depth of 9 m (30 ft). Major equipment and systems include:

- fuel basket handling and storage crane
- fuel storage baskets for PWR and BWR assemblies (see Figures 5.7.11 and 5.7.12)
- fuel storage racks for the storage baskets
- basin water cooling system
- basin water cleanup and treatment systems

A 50-MTHM surge storage pool feeds a 2000 MTHM/yr packaging facility and provides short-term storage for special canisters that contain failed fuel assemblies awaiting expedited transfer to the packaging facility. A transfer canal is provided from the cask unloading pools (CUPs) into the surge storage pool; another transfer canal runs from the surge storage pool to the packaging facility feeder canals.

Support Systems. These support systems ancillary to FSB operations are the same as those described in Section 5.7.1.4.

Facilities Not Included. The spent fuel shipping casks are not included within the scope of this facility and are described in Section 6.2.

Shielding and Remote Handling Equipment. The facility is designed for a combination of contact and semiremote operations using hand tools, cranes, and carts. Semiremote operations are performed underwater where they can be seen and controlled from above. The pool water and shipping cask provide radiation shielding for the facility operators. The shielding is designed to keep the average dose rate to operating personnel below 1 mrem/hr.

5.7.2.5 Operating and Maintenance Requirements for the Modified ISFSF

The reference facility is designed to operate 24 hours a day, 7 days a week, year round. The facility receives 2000 MTHM/yr; 450 rail casks and 500 truck casks. Based on the cask unloading time cycles in Table 5.7.7, the reference facility can accommodate the required fuel unloading by operating 300 days a year and handling up to 3 rail casks and 1 truck cask in the facility at one time. Proper sequencing of the unloading cycles is required, for example, only two casks can be in the unloading phase and only one cask can be in the decontamination phase at any one time.

Hazardous Materials. The only chemicals used in the reference process are nitric acid, caustic, and other decontaminating agents; these substances are handled according to safe industrial practices. Organic ion exchange resins are used for radionuclide cleanup of pool water and for cleaning a portion of the cask wash water. These resins are periodically replaced and do not present a safety hazard.

Staffing. Estimated staffing requirements for the facility are shown in Table 5.7.19.

TABLE 5.7.19. Staffing Requirements for the Modified ISFSF

Job Description	Personnel Required, man-yr/yr
Operators	66
Maintenance	9
Radiation monitors	5

Supplies and Utilities. Table 5.7.20 shows the essential materials used in facility operations. Table 5.7.21 lists the utilities required to operate the facility.

TABLE 5.7.20. Supply Requirements for the Modified ISFSF

Material	Use	Annual Requirement, m^3
5% sodium hydroxide	Ion exchange bed regeneration	570
5% nitric acid	Ion exchange bed regeneration	380
Detergent		
SP-210[a]	Decontamination	15
Powdered detergent	Cleaning	0.26

a. SP-210 is a decontamination agent of a proprietary composition containing detergent, wetting, and rinsing agents. It is used as a 10% by weight solution in water. The decontamination solution has a pH of 10.9 and a specific gravity of 1.05.

TABLE 5.7.21. Utility Requirements for the Modified ISFSF

Utility	Use Rate	Annual Requirement
Electricity	3000 kW	2.6×10^7 kWh
Water consumed	680 m^3	2.5×10^5 m^3
Steam	1.3×10^5 kg/day	4.8×10^7 kg
Coal	1.3×10^4 kg/day	4.8×10^6 kg

5.7.2.6 Secondary Radioactive Wastes for the Modified ISFSF

Secondary radioactive wastes associated with the reference facility are shown in Table 5.7.22.

TABLE 5.7.22. Secondary Radioactive Waste for the Modified ISFSF

Description	Volume, m^3/yr	Radioactivity Factor[a] Activation Products	Fission Products
Combustible and compactable waste	1500	All 7×10^{-3}	All 7×10^{-3}
Wet wastes	60	All 1.0	All 1.0
Failed equipment and noncombustible waste	150	All 6×10^{-4}	All 6×10^{-4}

a. Fraction of total in secondary waste activity in indicated waste category. Obtain total secondary waste activity from Table 3.3.4 as follows:
   1) for receiving; 500 times the values listed in the third column, plus 1500 times the values listed in the third column adjusted for an additional six years of decay (see Table 3.3.5 for factors).
   2) for storing; 3000 times the values listed in the fourth column.

5.7.2.7 *Emissions from the Modified ISFSF*

Facility emissions are characterized in Table 5.7.23. The radionuclide releases are based on the same estimates and assumptions as those used in Section 5.7.1.7.

TABLE 5.7.23. Emissions from the Modified ISFSF

Emissions	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere[a] Receiving[b]	Storage[c]
Gaseous	Facility and process air and vaporized excess water	4.0×10^9 m^3	$^3H = 2 \times 10^{-6}$	1×10^{-6}
			$^{14}C = 3 \times 10^{-6}$	1×10^{-8}
			$^{85}Kr = 6 \times 10^{-5}$	7×10^{-7}
			$^{129}I = 1 \times 10^{-7}$	9×10^{-9}
			$Cs = 7 \times 10^{-11}$	9×10^{-12}
			Other FP $= 2 \times 10^{-12}$	2×10^{-13}
			Actinides = negligible	negligible
			Activation products $= 2 \times 10^{-10}$	2×10^{-11}
	Minor accident integrated annual release		Included above	Included above
Cooling tower water	Evaporated (T = 38°C)	2.1×10^8 kg		
	Drift (T = 38°C)	1.0×10^6 kg		
	Blowdown (T = 27°C)	3.6×10^7 kg		
Other	Heat	$\leq 1.4 \times 10^{11}$ MW-hr (4.8×10^{11} BTU)		

a. Fraction of input activity (Table 5.7.2) released to atmosphere. Apply these factors to the facility inventory obtained by multiplying the values in Table 5.7.2 by the number of MTHM received or in storage in a given year. Use 0.5 year age for receiving and 3.5 year age for storage. Includes DFs in process off-gas system and process concentrator where applicable. Release assumed to be uniform over the year.
b. Release results from damage during handling. Release assumed to occur shortly after damage.
c. Fraction of input activity released during each year of storage.

5.7.2.8 Decommissioning Considerations for the Modified ISFSF

Decontamination and decommissioning considerations are the same as for the unmodified facility (see Section 5.7.1.8).

5.7.2.9 Postulated Accidents for the Modified ISFSF

Accident considerations for the modified storage facility are the same as for the unmodified storage facility (see Section 5.7.1.9) except handling, rail cask venting, and dropped fuel assembly accident frequencies, which double due to an increase in capacity to 2000 MTHM/yr compared to 1000 MTHM/yr. (See Accident No. 5.7.6, 5.7.7, 5.7.8 and 5.7.11).

5.7.2.10 Costs for the Modified ISFSF

Estimates have been made, in mid-1976 dollars, of capital, operating and levelized unit costs. A complete description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Costs. The total capital cost, which is given in Table 5.7.24, includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation with the exception of working capital.

TABLE 5.7.24. Capital Cost Estimate for the Modified ISFSF

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		130	31,800	1,500	33,300
Buildings and structures		2,170	16,300	26,000	42,300
Bulk materials		980	9,700	11,800	21,500
Site improvements		140	800	1,700	2,500
Subtotal of direct site construction costs		3,420	58,600	41,000	99,600
Indirect site construction costs	900	680	15,000	19,900	34,900
Total field cost	900	4,100	73,600	60,900	134,500
Architect-engineer services					27,000
Subtotal					161,500
Waste management facilities					14,000
Owner's cost					48,500
Total facility cost					224,000
Estimate accuracy range					±30%

Note: The cost for PWR and BWR storage baskets (all fabricated from stainless steel) are included in the facility cost estimates. The estimated unit costs for these items are:

PWR storage baskets - $9,000 BWR storage baskets - $14,000

These costs are based on procurement in lots of 100 or more.

Operating Costs. The operating cost components for modified water basin storage of unpackaged spent fuel are shown in Table 5.7.25. Direct labor costs are based on manpower estimates given in Table 5.7.19. Process material costs are negligible. Utility costs are derived from requirements shown in Table 5.7.21. Annual maintenance materials costs are estimated at 3% of initial major equipment costs. Overhead and miscellaneous costs are estimated using the standard method described in Section 3.8. The estimates for the miscellaneous items are assumed to include all unidentified operating costs. The costs of taxes, insurance, and interest are included in the capital charge segment of the levelized unit cost.

TABLE 5.7.25. Operating Cost Estimate for the Modified ISFSF

Cost Element	Annual Costs, $1000s
Direct labor	1300
Process materials	0
Utilities	700
Maintenance materials	1000
Overhead	2000
Miscellaneous	600
Total	5600
Estimate accuracy range	+50% -25%

Levelized Unit Costs. The modifications made to the water basin storage facility and the costs for those modifications are due to the facility being designed to service a contiguous spent fuel packaging facility. Levelized unit costs (Table 5.7.26) are calculated for only the incremental water basin modifications and these are assigned to spent fuel packaging in Section 5.7.3.10. These costs are based on the additional capital ($24 million) and operating costs ($1.25 million) and the spent fuel packaging throughput. In addition, 10% of the spent fuel storage costs which is equivalent to 300 MTHM storage are allocated to packaging to provide for additional surge storage. The costs are based on a 15-year period of operation including a 2-year startup period. Costs are estimated for both private ownership and Federal government ownership. Costs of private ownership are about twice that of Federal ownership because of tax payments and higher costs of capital.

TABLE 5.7.26. Levelized Unit Costs for Incremental Storage Basin Facilities to Service a Spent Fuel Packaging Facility

Cost Element	Unit Cost, $/kg	
	Private Ownership	Federal Ownership
Levelized capital charge	2.80	1.00
Levelized operating charge	0.70	0.70
Levelized charge for surge storage	2.50	1.30
Total levelized unit cost	6.00	3.00
Estimate accuracy range	±40%	±35%

5.7.2.11 Construction Requirements for the Modified ISFSF

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating this impact.

Project Schedules and Construction Manpower. The estimated schedule for engineering, procurement, and construction is identical to the estimates for the unmodified facility as given in Figure 5.7.17, Section 5.7.1.11. Figure 5.7.24 shows the construction labor force schedule for the modified storage facility.

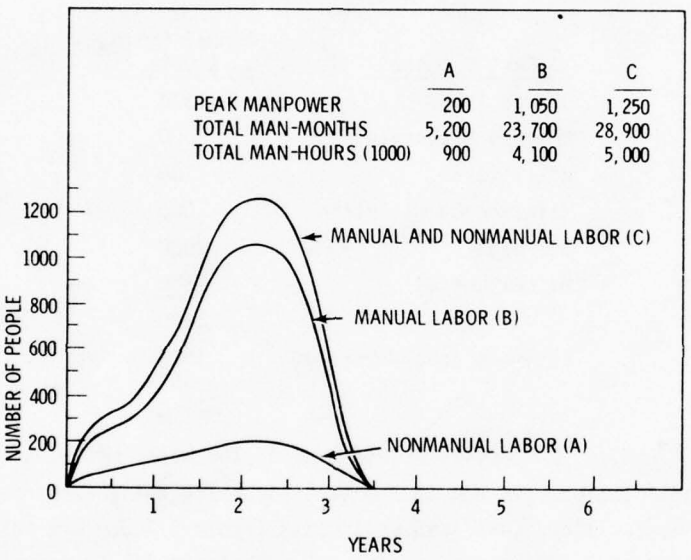


FIGURE 5.7.24. Construction Labor Force Schedule for the Modified Facility for Water Basin Storage of Unpackaged Spent Fuel

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the modified storage facility, while offsite costs are those for all services provided, materials purchased, and equipment fabricated or assembled elsewhere. The distribution of total costs in these categories is as shown below:

	Costs, $1000s
Onsite costs	74,000
Offsite costs	150,000
Total	224,000

Site Requirements. Siting requirements are the same as for the unmodified facility (see Section 5.6.1.4) and must be compatible with those of the FPF (see Section 5.7.3.4). The reference facility is located on 405 ha (1000 acre) site. Approximately 10 ha (25 acres) must be cleared for facility installations. An additional 4 ha (10 acres) are required for construction storage, work yards, temporary buildings, and labor parking.

Water. About 60×10^6 ℓ (16×10^6 gal) of water are required during construction.

Construction Materials. Major material requirements for facility construction are:

Concrete	23,000 m^3	(30,000 yd^3)
Steel	10,900 MT	(12,000 tons)
Copper	27 MT	(30 tons)
Zinc	64 MT	(70 tons)
Lumber	1,300 m^3	(550 MFBM)

Energy. Energy resources used during construction are:

Propane	570 m^3	(150,000 gal)
Diesel fuel	5,700 m^3	(1,500,000 gal)
Gasoline	3,790 m^3	(1,000,000 gal)
Electricity		
Peak demand	1,500 kW	
Total consumption	2,800,000 kWh	

Transportation Requirements. Approximately 1.6 km (one mile) of new road are required to provide automobile and truck access from the nearest U.S. highway to the site. Approximately 3.2 km (2 miles) of new railroad spur are required for site railroad service.

5.7.2.12 Effects on Fuel Cycle Options on the Modified ISFSF

The need for a modified water basin storage facility would depend on whether or not the fuel is packaged for interim storage. If the fuel is to be stored in packaged form, the modified water basin storage facility would be needed in combination with a fuel packaging facility. For more information, see Section 5.7.3.12, which discusses effects of fuel cycle options on the fuel packaging facility.

5.7.3 Spent Fuel Packaging

As shown in Figure 5.7.25, the reference concept involves an initial storage of spent LWR fuel assemblies for a total period of 6.5 years at either nuclear power plant basins, offsite ISFSFs, or the onsite modified ISFSFs adjacent to a spent fuel packaging facility. After the initial 6.5 year storage the spent fuel is transferred to a facility for packaging in steel containers to provide additional containment of the fuel for extended storage or for shipment to a final repository. The package is designed to provide an additional barrier to the release of radionuclides during handling and storage under normal and design basis accident conditions. The package is also compatible with nuclear waste disposal after the storage period.

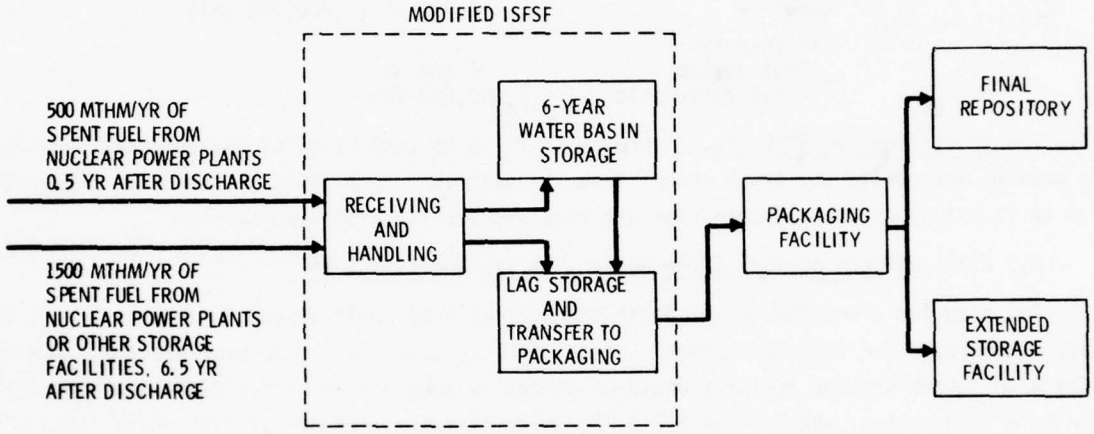


FIGURE 5.7.25. Reference Spent Fuel Packaging and Storage System

With current water basin storage of spent fuel, the fuel assemblies are not normally packaged. Occasionally, however, failed spent fuel assemblies are overpacked to contain radionuclide activity. It is only recently that fuel packaging for storage studies have been initiated because government policy has given increased emphasis to the option of not reprocessing LWR fuels. Some studies and some experience in packaging solidified high-level waste (SHLW) and fuels other than LWR are applicable to packaging LWR fuel. There appear to be no serious technological problems related to spent fuel packaging but concept optimization studies and testing have yet to be carried out. Approximately 2 to 4 years would be required to verify corrosion resistance of container materials, and optimize container design. The design and construction of a packaging facility could proceed concurrently with the receiving and storage facility design and construction.

5.7.3.1 Alternatives for Spent Fuel Packaging

Most of the available technology concerning packaging of spent fuel has been developed for fuels other than those from LWRs. Conceptual designs have been developed for facilities that package CANDU spent fuels,[10] Fast Flux Test Facility (FFTF) spent fuel,[11] and canisters of solidified HLW.[12] A facility for packaging and storing fuel from the Fort St. Vrain and Peach Bottom high-temperature gas-cooled reactors and from the Rover nuclear rocket program has been built at the Idaho Chemical Processing Plant.[13]

Atomic Energy of Canada, Limited (AECL) has developed several packaging concepts for use with CANDU fuels.[10,14] Three of the concepts involve fuel encapsulation in mild steel containers under helium atmospheres. These packaging concepts are planned for surface silos but could be used with other storage concepts. In another packaging concept, six fuel assemblies are placed in a trefoil-shaped aluminum extrusion with zinc or aluminum as a filler material.[14] A helium filler protects against corrosion of fuel cladding and a potential UO_2-air interaction in failed fuel elements. Helium also provides improved heat transfer compared to air.

A concept developed for FFTF fuel[11] uses a helium-filled stainless steel container for each fuel assembly.

Graphite fuel assemblies from the Peach Bottom or Fort St. Vrain reactors are packaged in unsealed containers of 0.64-cm-thick carbon steel. They are stored in a forced-draft-cooled facility at the Idaho Chemical Processing Plant.[13]

Packaged fuel assemblies from several different reactors, including Hallam and Dresden, have been stored underwater at the Savannah River Plant for several years.[11,15]

The design of the reference spent fuel packaging facility (SFPF) uses the composite development and design experience mentioned above. Dried fuel is individually packaged in helium-filled metal containers which are seal welded. Storage environment and economics (stainless steel is assumed for water basin storage and mild steel for air cooled storage) determine the container material. The fuel elements are individually packaged because the heat transfer and criticality calculations were not available for multiple element storage. For a commercial facility, multiple element storage in a single container would be an attractive alternative.

5.7.3.2 Design Basis for Spent Fuel Packaging Facility

The following assumptions were made in the design of the reference SFPF:

- The facility is located adjacent to a modified ISFSF.
- Services and utilities are obtained from the adjacent modified ISFSF.
- The facility has a throughput of 2000 MTHM/yr.
- Only spent fuel from pressurized water reactors (PWR) and boiling water reactors (BWR) is processed.
- The fuel has cooled for at least 6-1/2 years after nuclear power plant discharge.
- The ratio of PWR assemblies to BWR assemblies is 2 to 3 (results from a 2:1 PWR:BWR capacity ratio).
- Packaging processes use remotely operated equipment, within shielded facilities.
- Spent fuel assemblies are packaged in individual carbon steel or stainless steel containers* (canisters).

* Selection of container and overpack material depends upon whether subsequent storage is in water or air; stainless steel is required for water storage.

- Canisters containing failed fuel are placed in a second container called an overpack.
- No more than 0.2% of the fuel assemblies are expected to contain failed fuel rods. However the facility is designed for a 2% failure rate.
- Steel overpacks and canisters are fabricated offsite.
- The facility has air locks and a controlled air leakage into the facility; effluent air is filtered.
- Air conditioning, other than heating in the winter, is not required in process areas.
- The facility has an area for receiving, handling, inspecting, and repairing empty canisters, and for storing a 2-month inventory of empty canisters and overpacks.

Safety. The primary design considerations of the spent fuel packaging facility are to protect the integrity of the fuel cladding and to safely transfer fuel assemblies into individual containers, for extended storage or transfer to a geologic repository. The facility will be designed to preclude the following as credible accidents:

- criticality
- dropping of heavy loads on fuel
- multiple massive ruptures of fuel assemblies by missiles
- loss of shielding
- complete loss of cooling.

Spent fuel handling structures and systems are designed to prevent excessive release of radioactivity while maintaining their functional integrity following any credible natural phenomena (earthquake, tornado, hurricane, flood, drought, etc.), any accidents (power loss, equipment failure, etc.), or any credibly related combinations of phenomena and accidents.

Use of Single Assembly Square Canister. Heat transfer calculations for the 6-1/2 year old fuel assemblies indicate that multiassembly packaging of BWR assemblies (four assemblies per package) is possible and that multiassembly packaging for PWR assemblies may be possible. However, the single-assembly/square canister is used here because it uses an evaluated critically safe configuration. Square canisters also allow placement of more packaged fuel in a shipping cask cavity for transportation, which results in significant transportation cost savings when moving the fuel to terminal storage in a canister. In an industrial facility, after additional analyses have been performed, round canisters and overpacks are an attractive alternative. Round canisters, of standard pipe size and structurally stronger, would be somewhat cheaper than square canisters.

5.7.3.3 Spent Fuel Packaging Facility Operations

The SFPF receives fuel assemblies into its heavily shielded air environment through the unpackaged spent fuel storage facility's water-filled transfer canal. After entry into the SFPF, the assemblies, which are handled only in a vertical position, are dried and sealed in helium-filled canisters. Packaged assemblies are then temporarily stored for about 2 days

and inspected to ensure that canisters are not leaking helium before they are transferred to another facility for extended storage. This spent fuel packaging process (Figure 5.7.26) is arranged into five process systems described below.

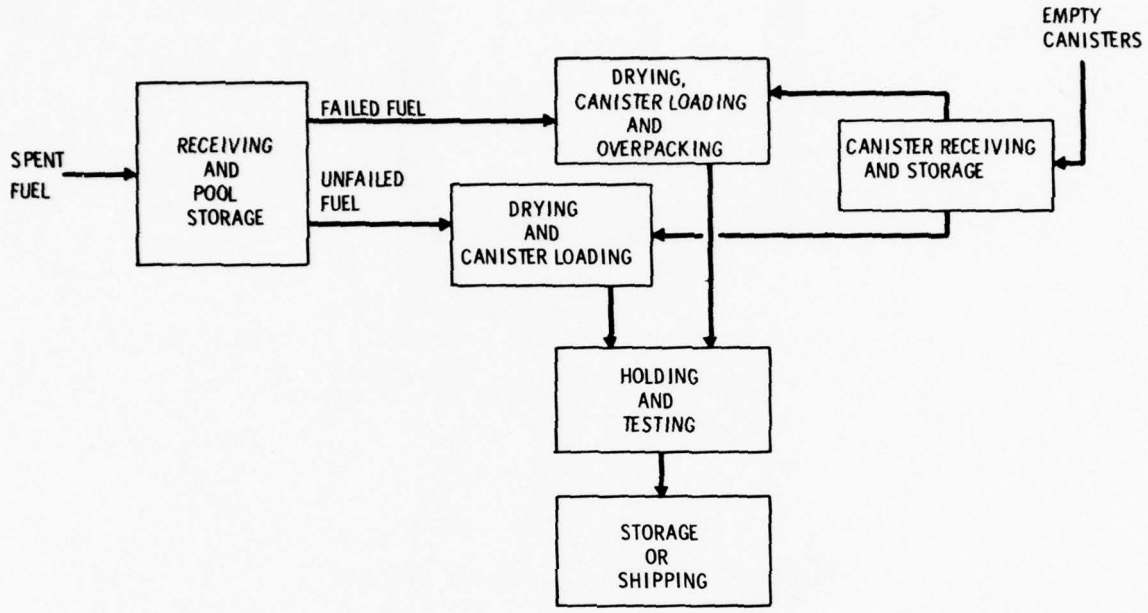
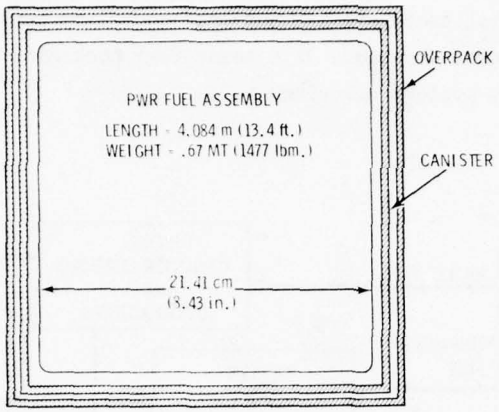


FIGURE 5.7.26. Major Process Functions of a Spent Fuel Packaging Facility

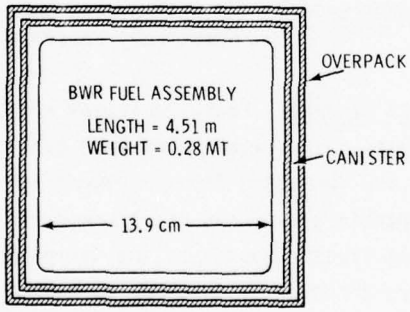
Container Receiving and Storage. Empty canisters and overpacks for failed fuel are received by truck from offsite. The exterior of each canister and overpack is washed and dried; then the containers are inspected for structural integrity and required dimensions and are leak tested. The acceptable containers are transferred to temporary storage areas near the appropriate fuel loading areas. Canisters and overpacks are assumed to be fully assembled as received, with top covers temporarily in place to keep interiors clean and dry during shipment to the packaging facility. Unacceptable containers are repaired or returned to the supplier.

Individual assembly canisters and overpacks are described in Figures 5.7.27 and 5.7.28 for PWR and BWR fuel, respectively. The structural material is 0.64 cm (1/4 in.) carbon steel or stainless steel. All fuel assemblies are packaged in a canister; only failed fuel also requires the overpack. The weight of an empty canister is 0.15 MT for BWR fuel and 0.23 MT for PWR fuel. The weight of an overpack is 0.18 MT for BWR fuel and 0.26 MT for PWR fuel. The top cover includes a knob or other device for handling the loaded canister. Provision is made for horizontal storage of canisters and overpacks until ready for transfer out of the receiving and storage area.



	CANISTER	OVERPACK
MATERIAL	304 SST OR CARBON STEEL	
WALL THICKNESS	0.635 cm (0.25 in.)	0.635 cm (0.25 in.)
OUTSIDE DIMENSION	24.13 cm (9.5 in.)	26.67 cm (10.5 in.)
INSIDE DIMENSION	22.86 cm (9.0 in.)	25.4 cm (10.0 in.)
LENGTH	4.876 m (16.0 ft)	5.03 m (16.5 ft)
WEIGHT	0.23 MT (502.0 lbm)	0.26 MT (573.0 lbm)

FIGURE 5.7.27. PWR Canister and Overpack



	CANISTER	OVERPACK
MATERIAL	304 SST OR CARBON STEEL	
WALL THICKNESS	0.635 cm (1/4 in.)	0.635 cm (1/4 in.)
OUTSIDE DIMENSION	16.51 cm (6.5 in.)	19.05 cm (7.5 in.)
INSIDE DIMENSION	15.24 cm (6.0 in.)	17.78 cm (7.0 in.)
LENGTH	4.88 m (16.0 ft)	5.03 m (16.5 ft)
WEIGHT	0.15 MT (330.0 lbm)	0.18 MT (405.0 lbm)

FIGURE 5.7.28. Boiling Water Reactor Fuel Canister and Overpack

Packaging Unfailed Fuel. Figure 5.7.29 shows the basic flow diagram for the two unfailed fuel packaging cells. Spent fuel assemblies are moved into the head end of each packaging cell from the modified unpackaged fuel storage facility through water canals. Up to 0.45 kg (1 lb) of water can adhere to fuel rod surfaces when fuel assemblies are discharged from water basin storage. This water must be removed before an assembly is packaged in a canister. Unfailed fuel assemblies are placed in thermally insulated floor wells in a closed loop, forced air system. Air circulates past the fuel rods, through a filter, and through a condenser unit which removes the water. Air activity is monitored to detect any failed fuel rods. Any failed fuel rods detected in the fuel drying area are transferred to the failed fuel packaging area.

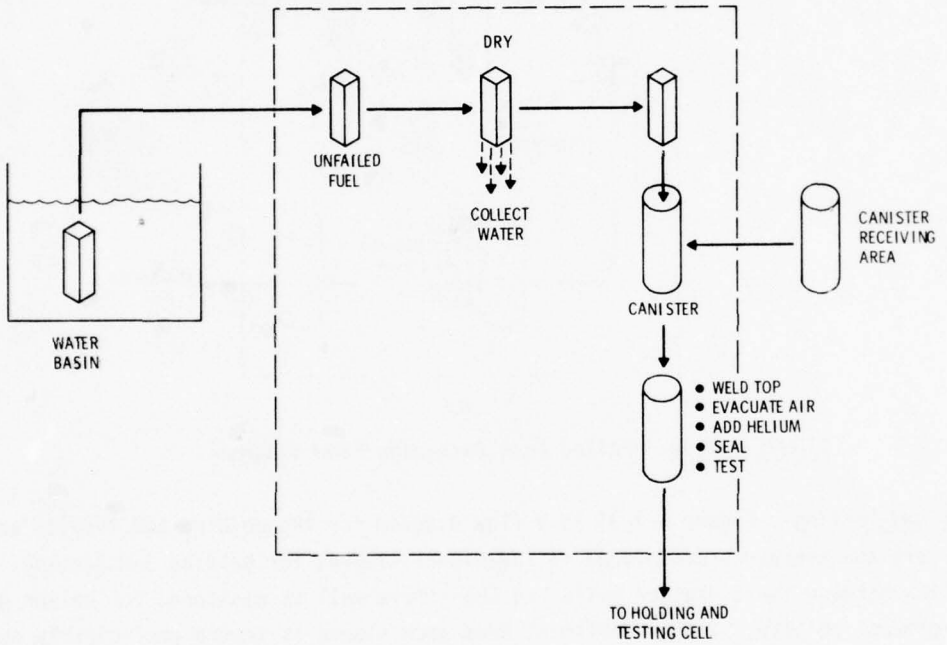


FIGURE 5.7.29. Unfailed Fuel Packaging Flow Diagram

Canisters are transferred from the receiving area and placed in racks. Fuel assemblies are transferred from the drying area and are packaged in the canisters. Canister top plates are welded in place, air is evacuated, helium is added to 5 psig, and the canisters are leak tested. Then the canisters are permanently sealed and are transferred to the holding and testing area.

Packaging Failed Fuel. Figure 5.7.30 is a basic flow diagram for the failed fuel packaging cell. Up to two or three failed spent fuel assemblies are packaged each week. The failed assemblies are removed from water basin storage, dried, and placed in canisters. A top is welded on each canister, and the air is evacuated and replaced by helium. The canister is permanently sealed, leak tested, decontaminated, sealed in an overpack, and transferred to the holding area. All operations with packaging of failed fuel (drying, welding, and helium addition) are performed in one cell.

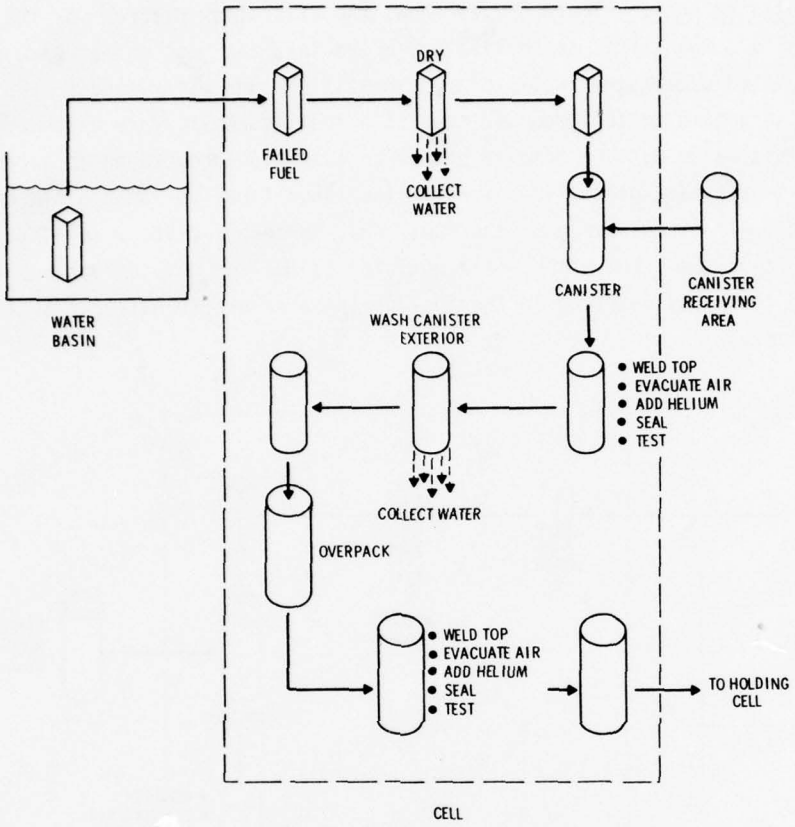


FIGURE 5.7.30. Failed Fuel Packaging Flow Diagram

Holding and Testing. *Figure 5.7.31 is a flow diagram for the holding and testing area.* Loaded canisters and overpacks are placed in individual sleeves for holding and testing. Upward air flow between the container walls and the sleeve wall is monitored for helium gas and fission product release. The air effluent from each sleeve is tested periodically over a 2-day period to detect helium and fission product leaks, which would indicate a faulty container. If no releases are detected, the containers are ready for final storage.

Transfer to Adjacent Storage Facility or Shipment Offsite. Packaged spent fuel is transferred to either the offsite loadout area or to an onsite storage facility. A canal transfer system is used to move spent fuel to an onsite water basin storage facility or, alternatively, an underground air tunnel is used if storage is in an onsite dry storage facility.

5.7.3.4 Description of the Spent Fuel Packaging Facility

The SFPF is adjacent to the modified ISFSF. This arrangement is shown in the plot plan in Figure 5.7.32.

General Facility Arrangement. The SFPF is arranged in three general spent fuel assembly handling areas: the spent fuel packaging area, the holding and testing area, and the offsite loadout area. These areas are shown on the key plan, Figure 5.7.33. Detailed plans and sections of the entire SFPF are shown in Figures 5.7.34 through 5.7.46.

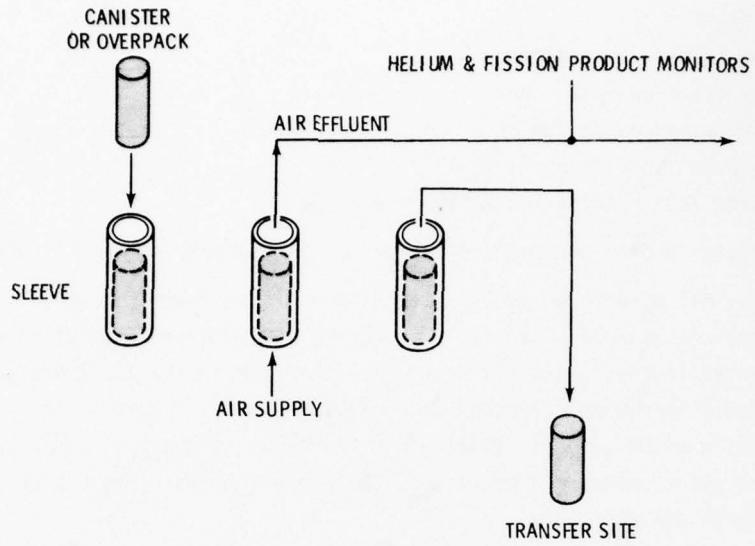


FIGURE 5.7.31. Holding and Testing Area Flow Diagram

Fuel Packaging Area. The fuel packaging area contains two unfailed fuel packaging cells and one failed fuel packaging cell, as well as associated ancillary and support areas. It is connected to the modified ISFSF by three water-filled transfer canals.

Holding and Testing Area. The principal feature of the holding and testing area is the holding cell, which is connected by transfer tunnels to the packaging cells, to the offsite loading area, and to the adjacent dry storage facility. Alternatively the holding cell may be connected to a water basin storage facility by canal.

Offsite Loading Area. The offsite loading area consists of the cask receiving and handling area, the packaged spent fuel loadout station, the container receiving and storage area, and associated service support facilities.

Operating and Support Area. The spent fuel handling cells are located in a three-story concrete building which houses the operating and support areas listed below:

- 1st floor areas
  - Cell air locks
  - Fuel drying equipment rooms
  - Supply blower mechanical room
  - Personnel facilities
  - Control room/computer room
  - Storage areas
  - Access aisles
  - Electrical room
  - Mechanical, electrical, and instrument shops
- 2nd floor areas
  - Operating aisles for all handling cells

- 3rd floor areas
  - Container transfer and storage
  - Container transfer hatch area
  - Warm crane maintenance
  - Warm equipment maintenance
  - Ventilation filter and exhaust blower station

A passenger elevator and an equipment elevator are provided to serve all three floor levels.

Structures. All structures in the packaging building where the spent fuel is handled and processed are designed as Category I, including the unfailed and failed spent fuel cells, the holding and testing cell, and all spent fuel transfer canals and tunnels. These structures are of reinforced concrete construction with shielding walls 1.22 m (4 ft) thick. The warm maintenance areas and the exhaust filter and blower station are also Category I and are adequately shielded with concrete. The rest of the process building is standard commercial reinforced concrete construction.

All portions of the offsite shipping facility that must protect the integrity of the packaged spent fuel are Category I. These areas include the transfer tunnel, the cask loading cell, the shipping cask cell, the control room, the exhaust filter and blower station, and the shipping cask crane and its support structure.

The canister receiving building is of standard commercial construction, with insulated metal wall panels and insulated metal roof decking.

Systems and Equipment. Described below are systems and equipment for the spent fuel packaging facility.

Fuel Packaging: Unfailed Spent Fuel. Both of the unfailed fuel cells have 12 drying wells, 12 canister holding racks, and 2 welding stations. In-cell handling and transfer of the fuel assemblies and the canisters are accomplished with overhead bridge cranes, a power manipulator, a motorized cart to and from the fresh canister air lock, and a motorized cart for transfer to the holding and testing cell. The use of two independent cells permits cell maintenance without total loss of production.

Fuel Packaging: Failed Spent Fuel. Because leakage from failed spent fuel assemblies can result in radioactive contamination in the fuel packaging cell, the cell's front end has dry and wet cleanup facilities and equipment, including a vacuum cleaning system, master slave manipulator, decontamination solution washing equipment, and TV cameras. The failed fuel cell is equipped with two drying wells, two canister and overpack holding racks, two remote welder and helium test stations, and one decontamination chamber station. The same in-cell handling process is used as for the unfailed fuel cells. Packaged spent fuel is transferred from the packaging cell through air tunnels to the holding and testing cell by motorized cart.

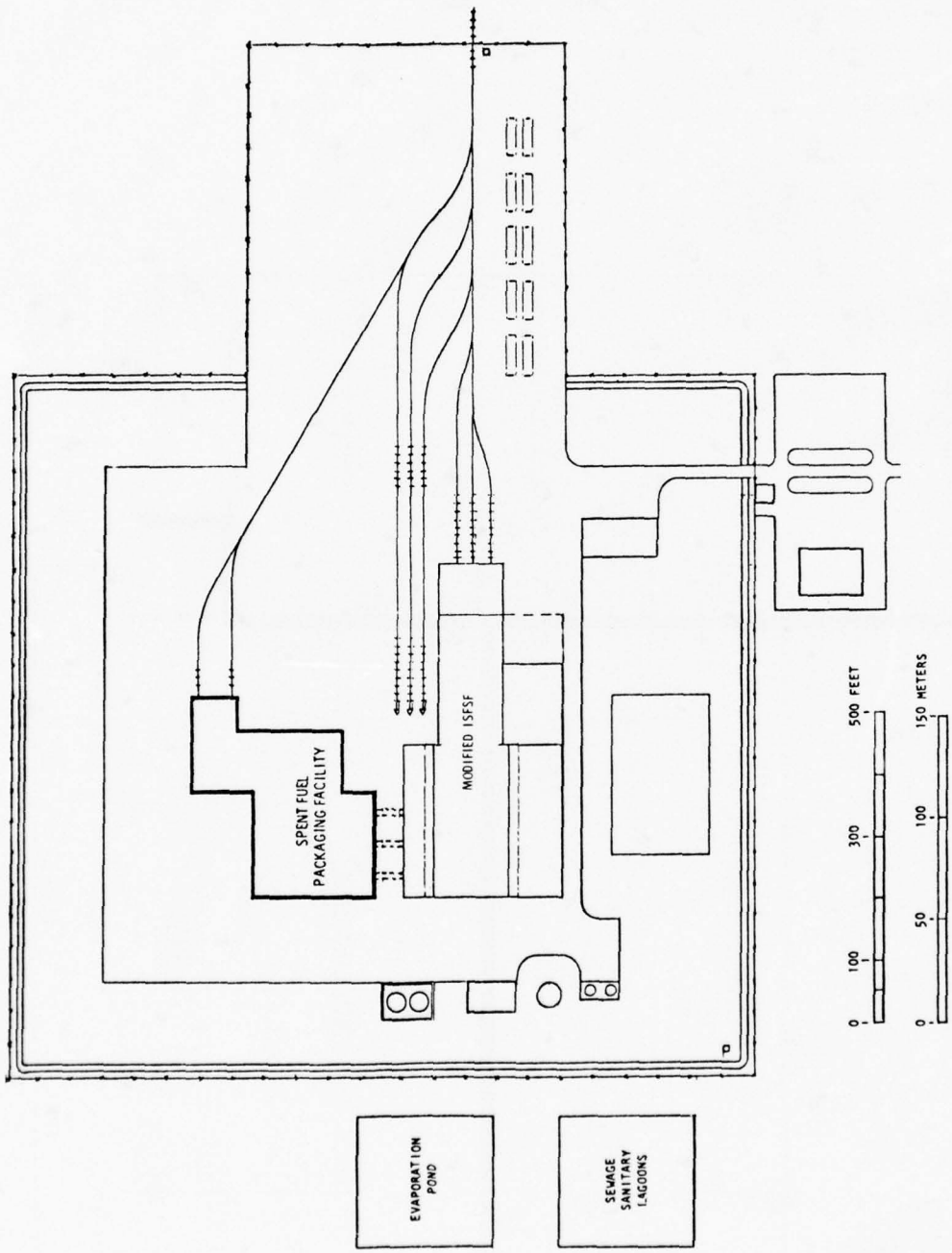


FIGURE 5.7.32. SFPF, Plot Plan

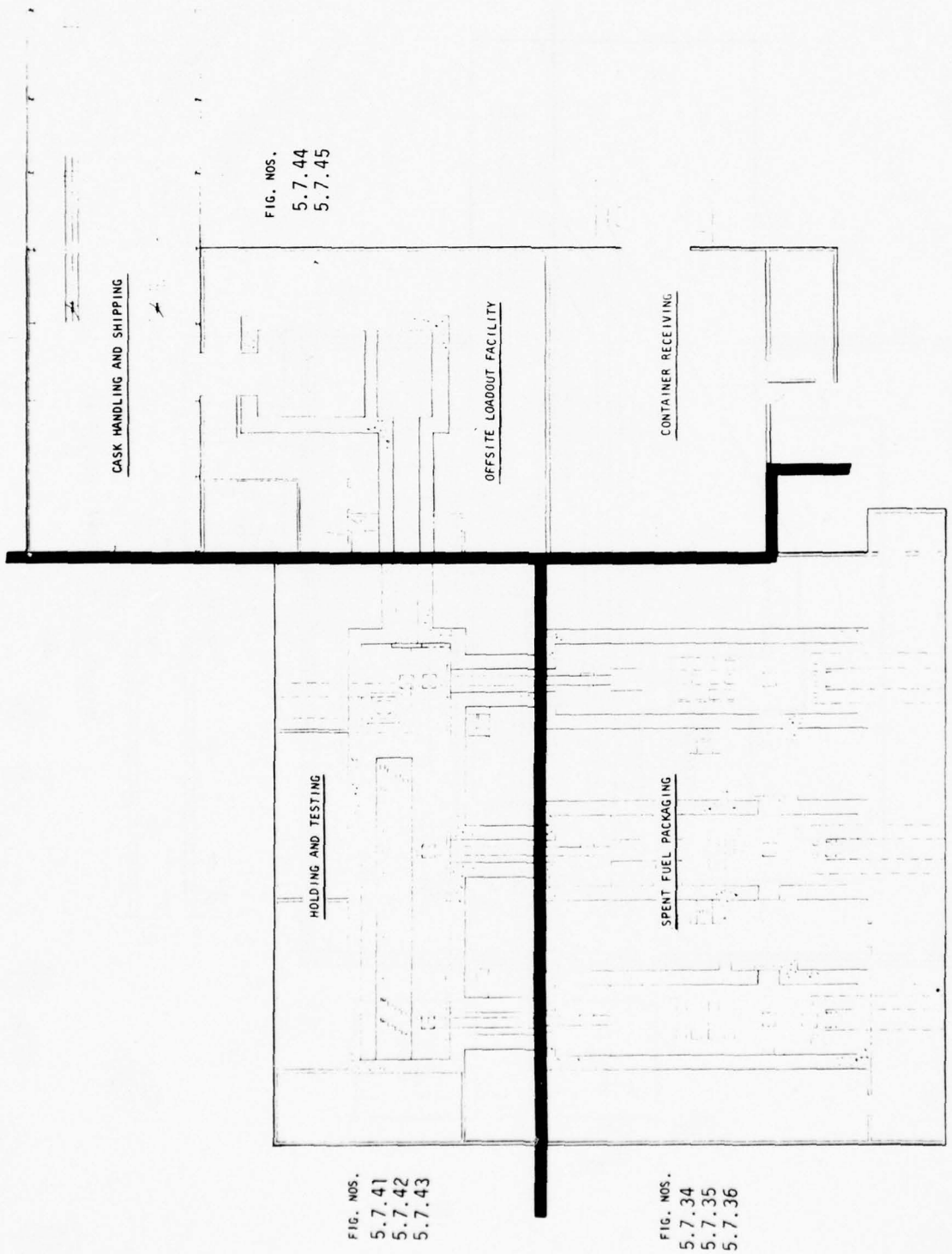


FIGURE 5.7.33. SFPF, Key Plan

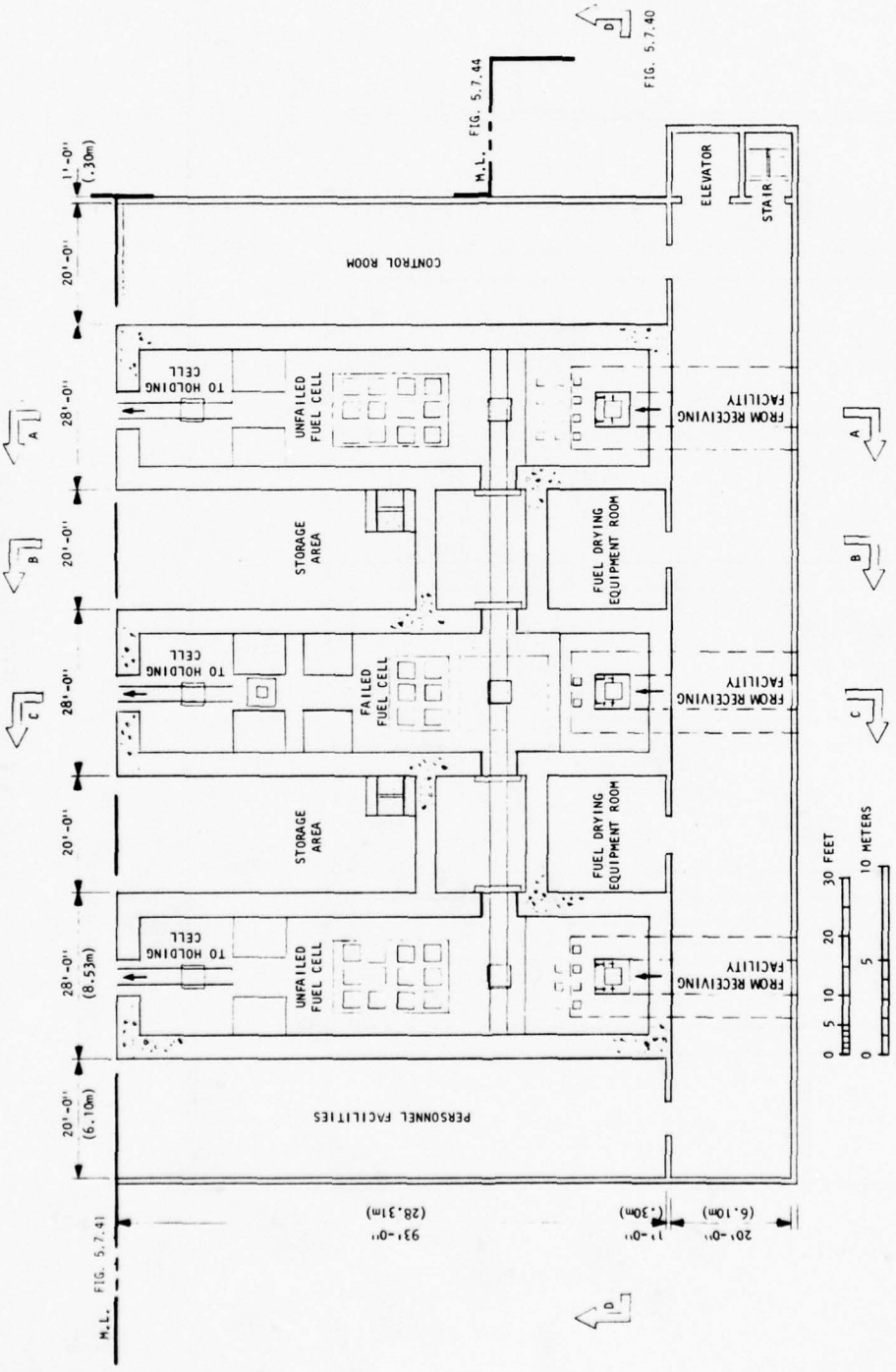


FIGURE 5.7.34. SFPF Packaging Area, 1st Floor Plan

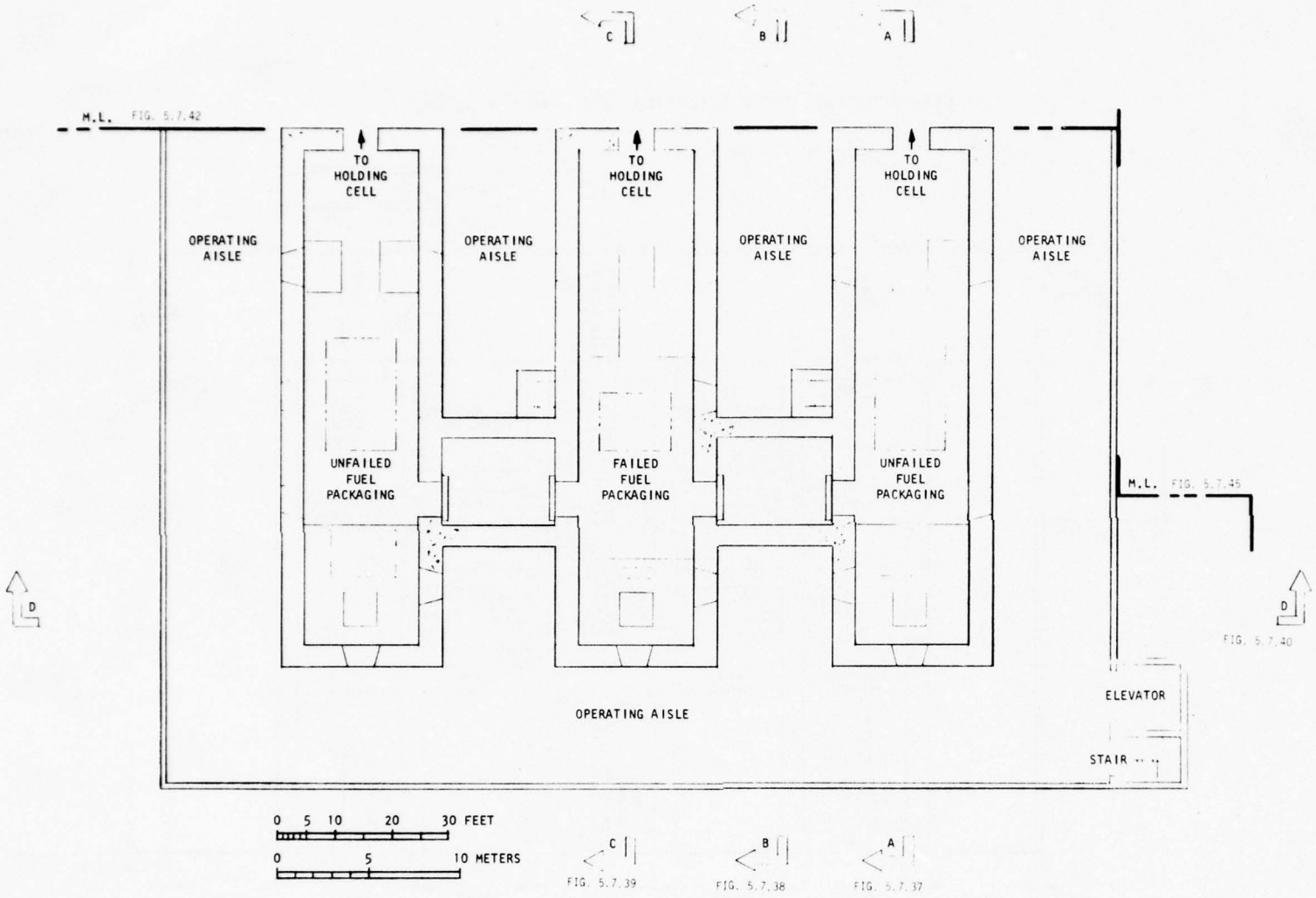


FIGURE 5.7.35. SFPF Packaging Area, 2nd Floor Plan

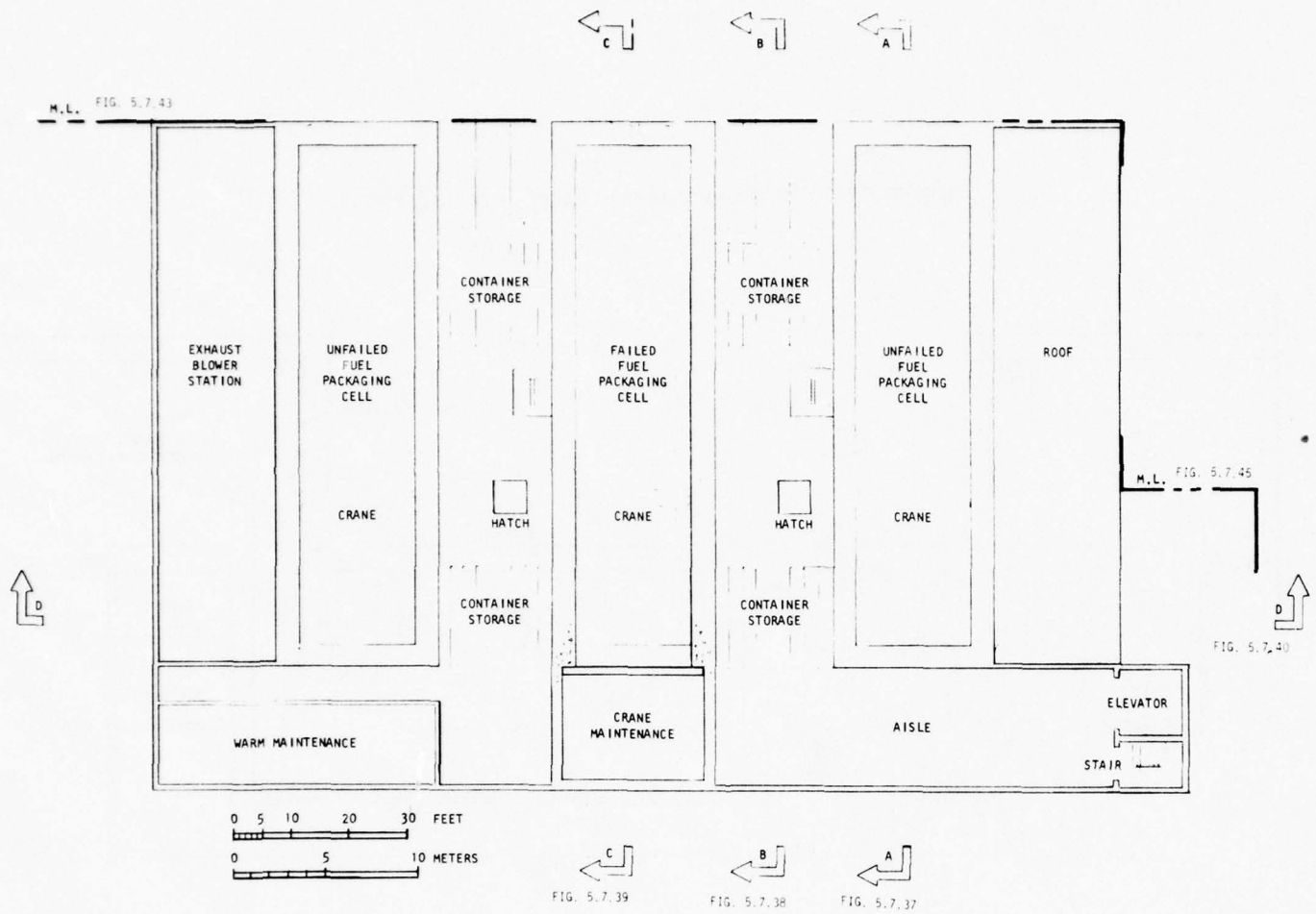


FIGURE 5.7.36. SFPF Packaging Area, 3rd Floor Plan

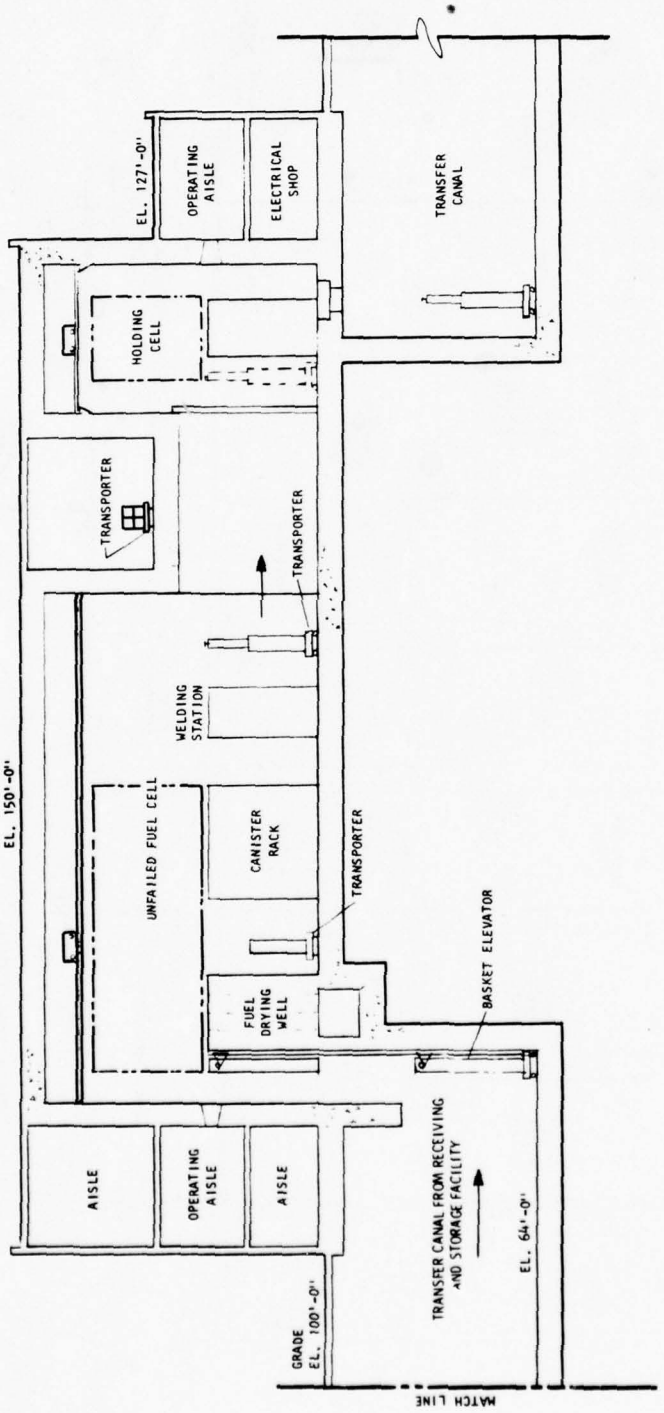


FIGURE 5.7.37. SFPF Packaging Building, Section A-A

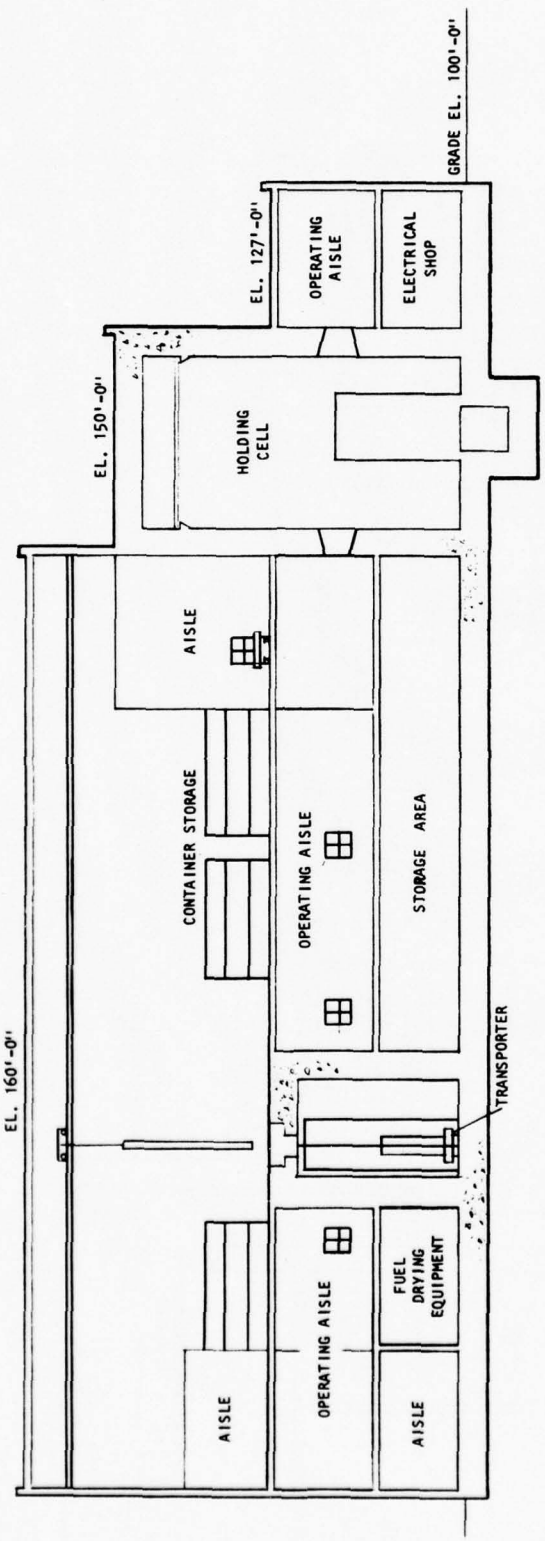


FIGURE 5.7.38. SFPF Packaging Building, Section B-B

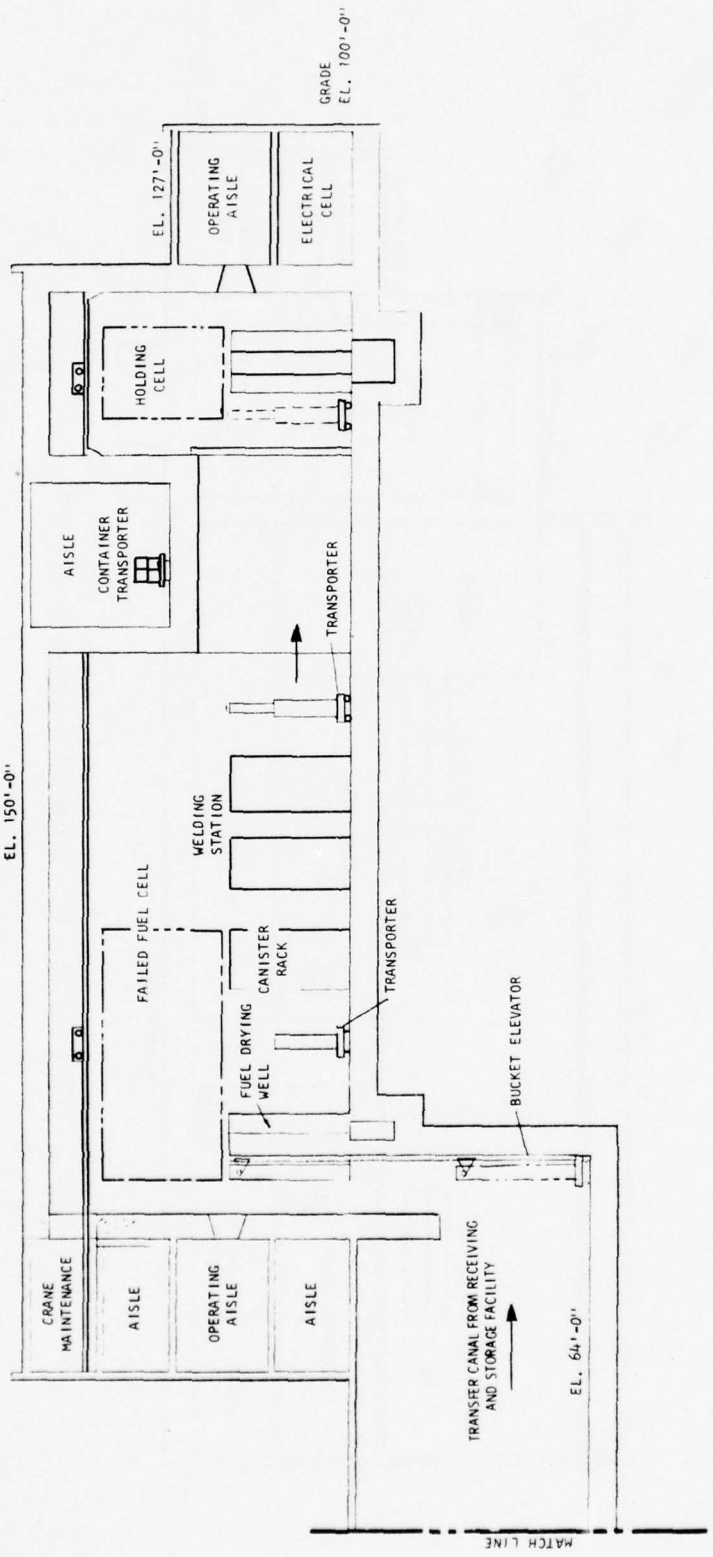


FIGURE 5.7.39. SFPF Packaging Building, Section C-C

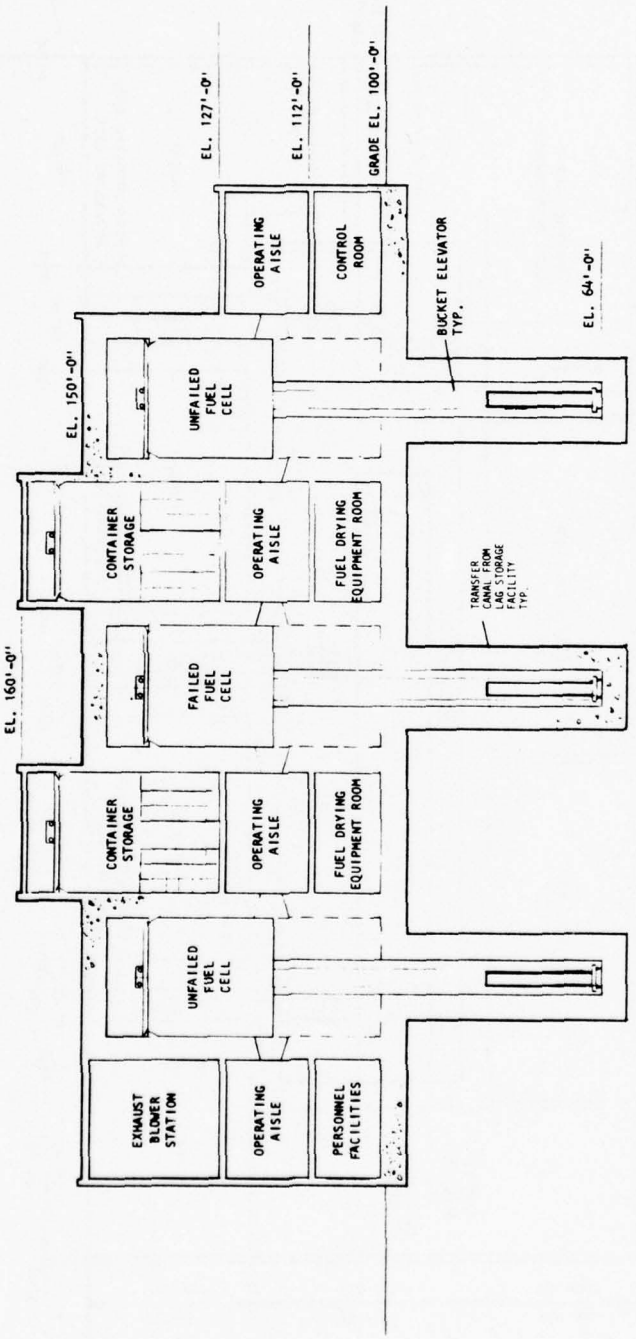


FIGURE 5.7.40. SFPF Packaging Building, Section D-D

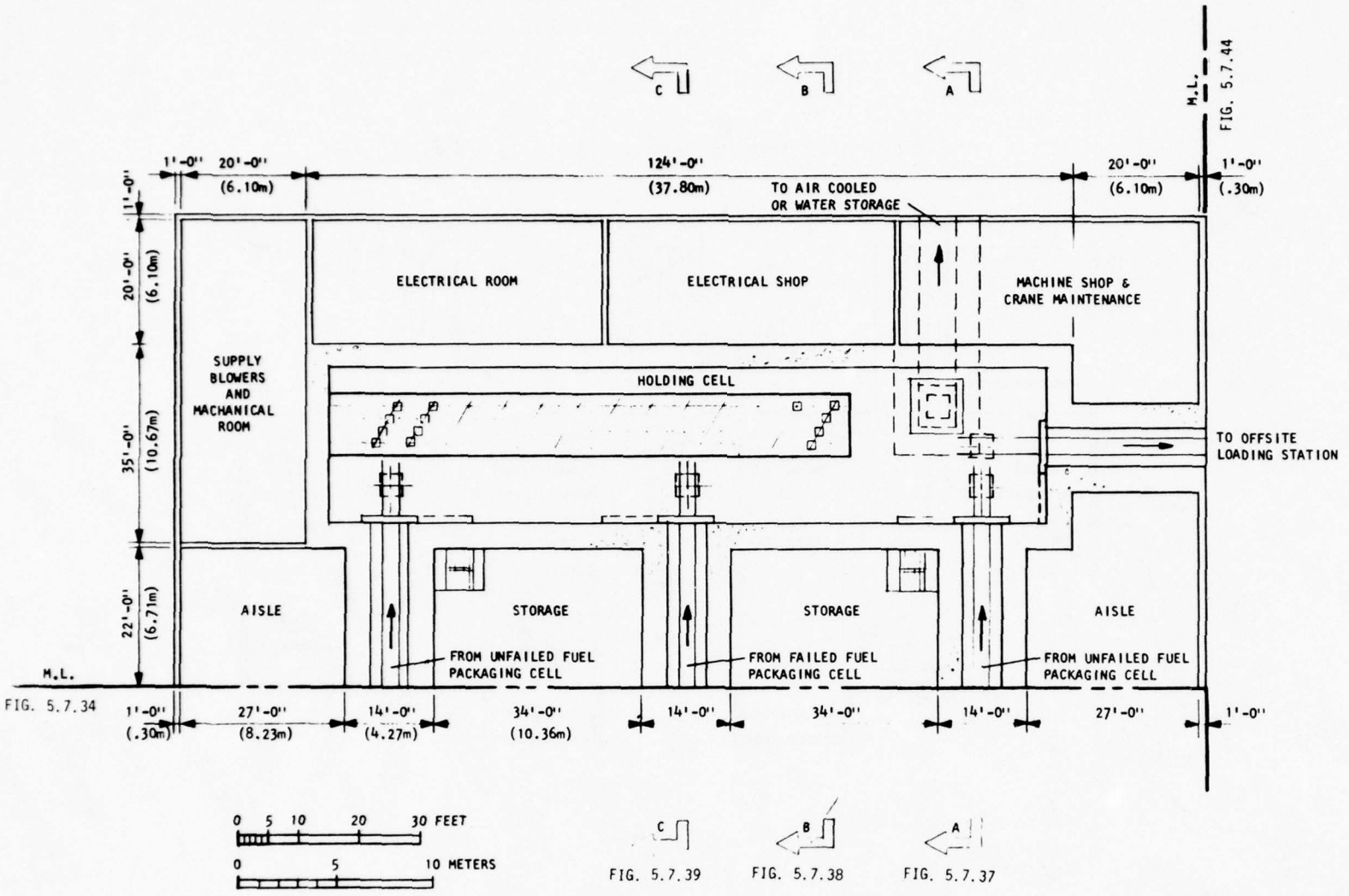


FIGURE 5.7.41. SFPF Holding and Testing Area, First Floor Plan

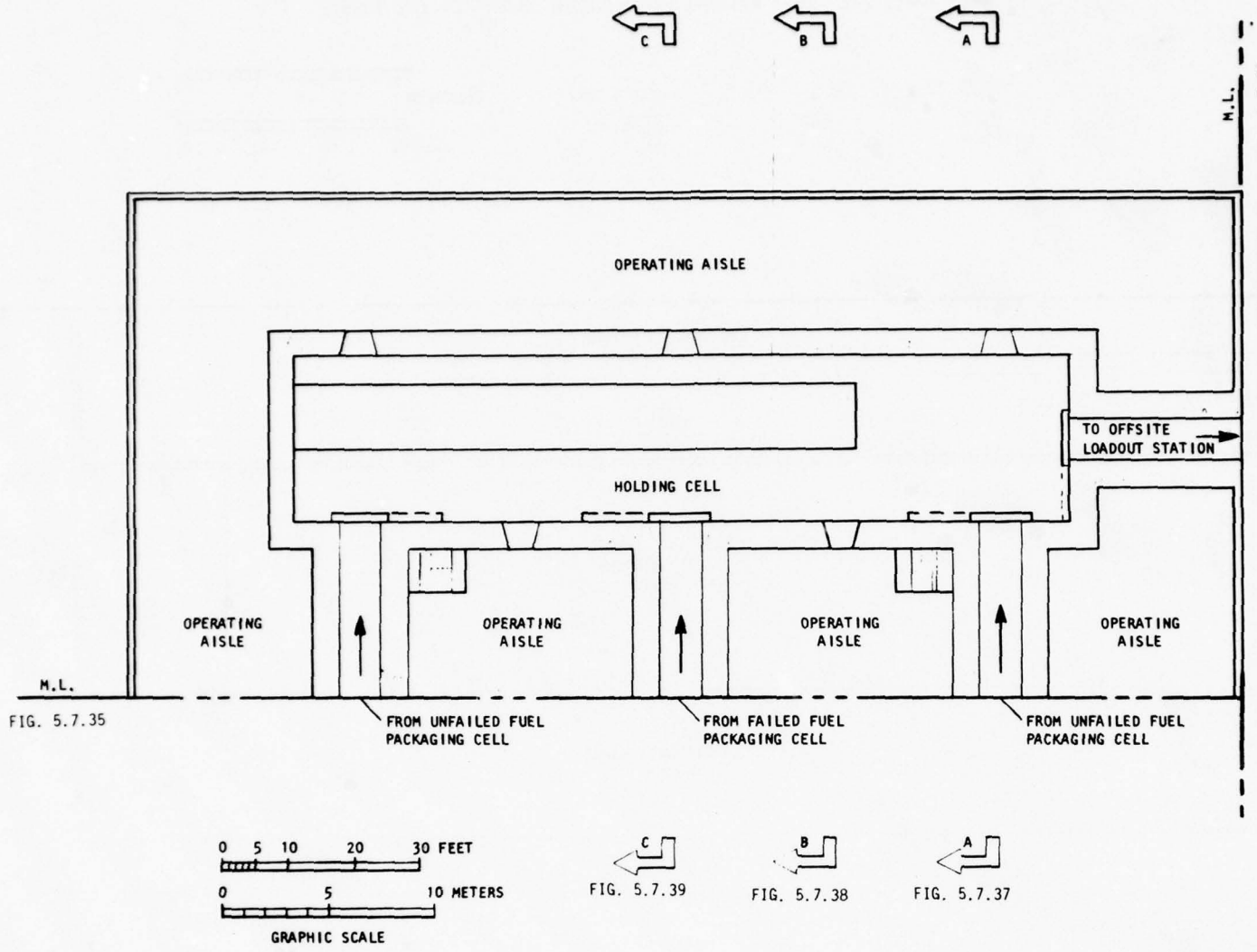


FIGURE 5.7.42. SFPF Holding and Testing Area, 2nd Floor Plan

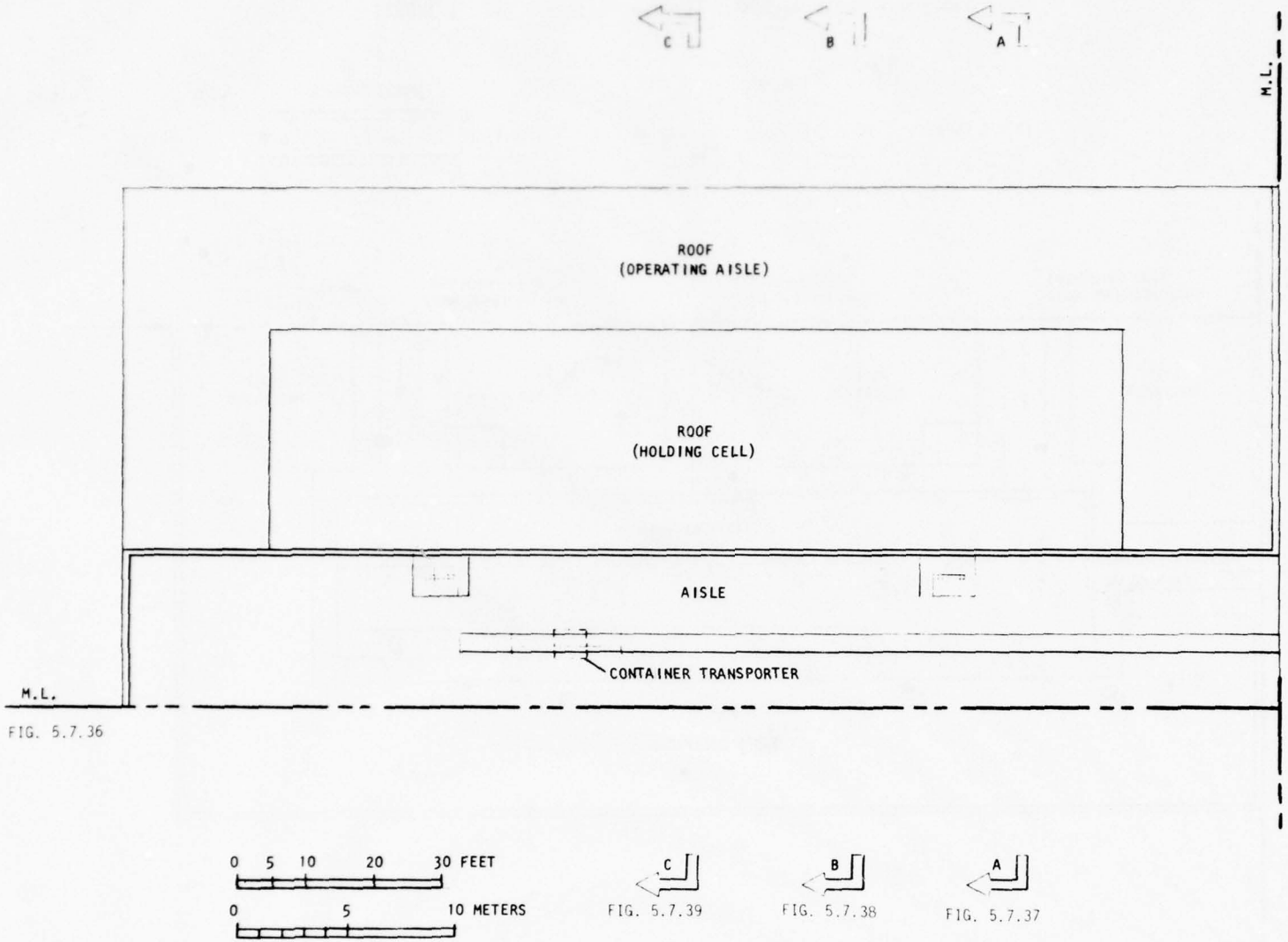


FIGURE 5.7.43. SFPF Holding and Testing Area, 3rd Floor Plan

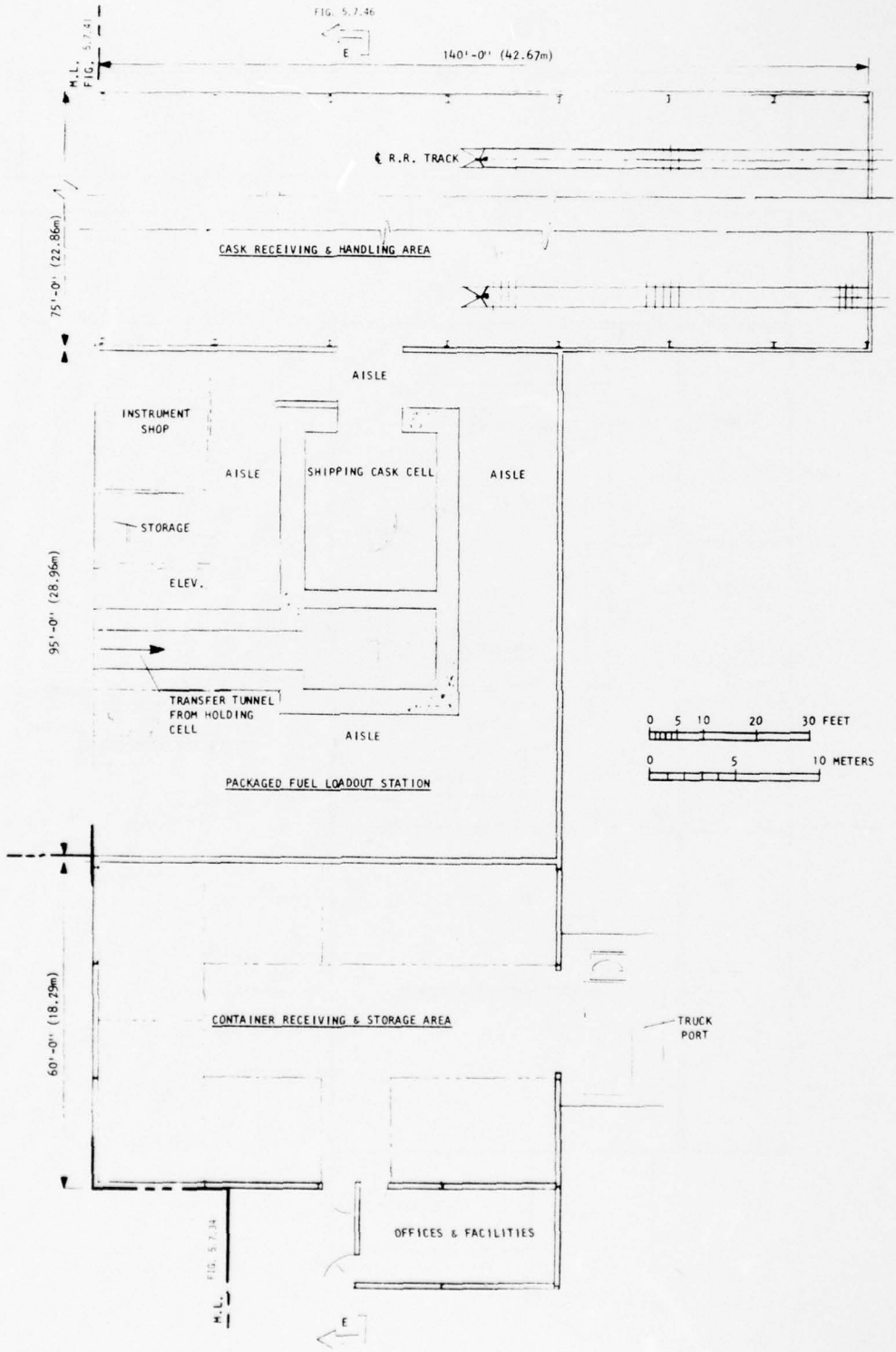


FIGURE 5.7.44. SFPF Container Receiving and Offsite Loadout Area, 1st Floor Plan

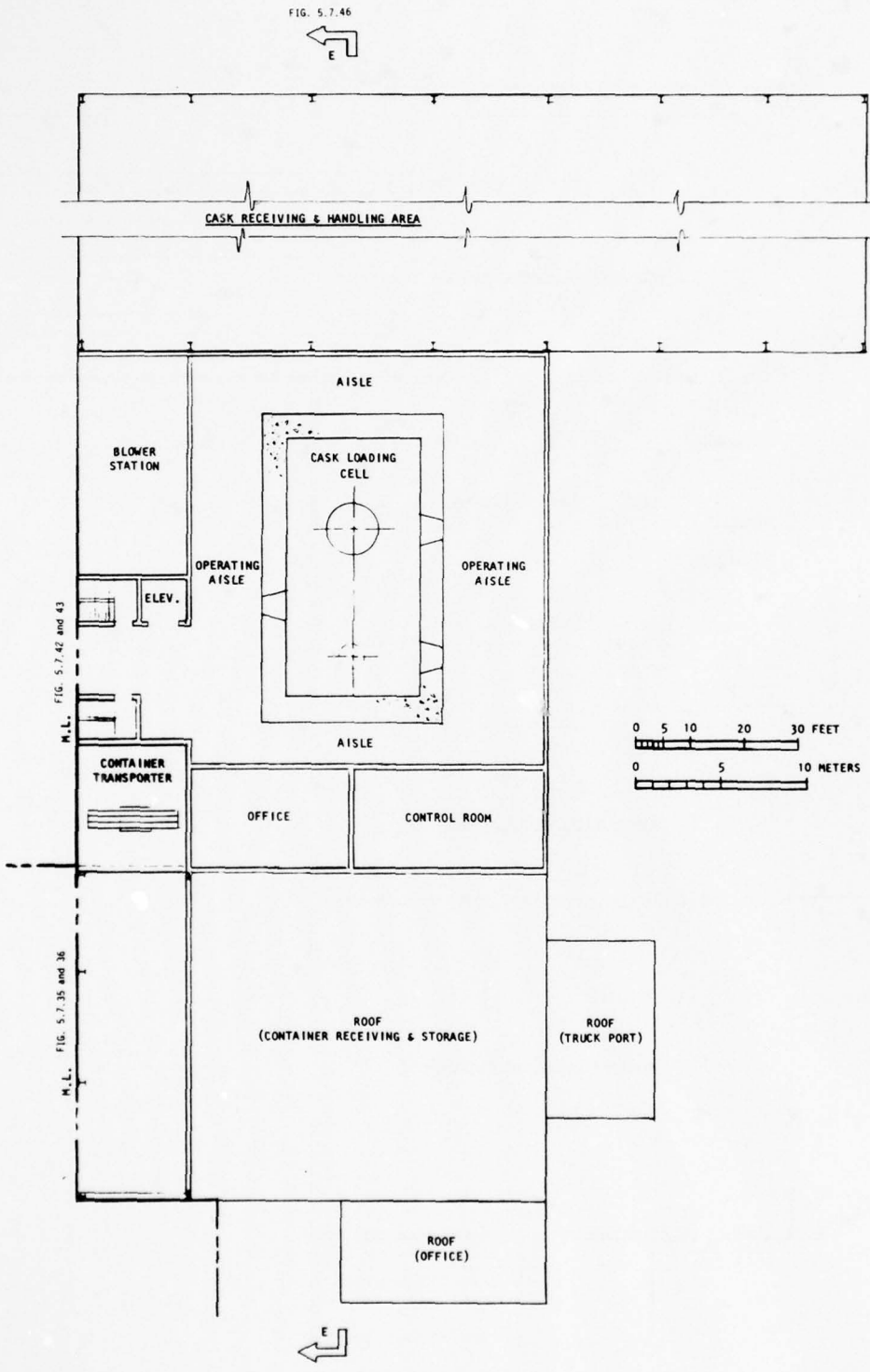


FIGURE 5.7.45. SFPF Container Receiving and Offsite Loadout Area, 2nd Floor Plan

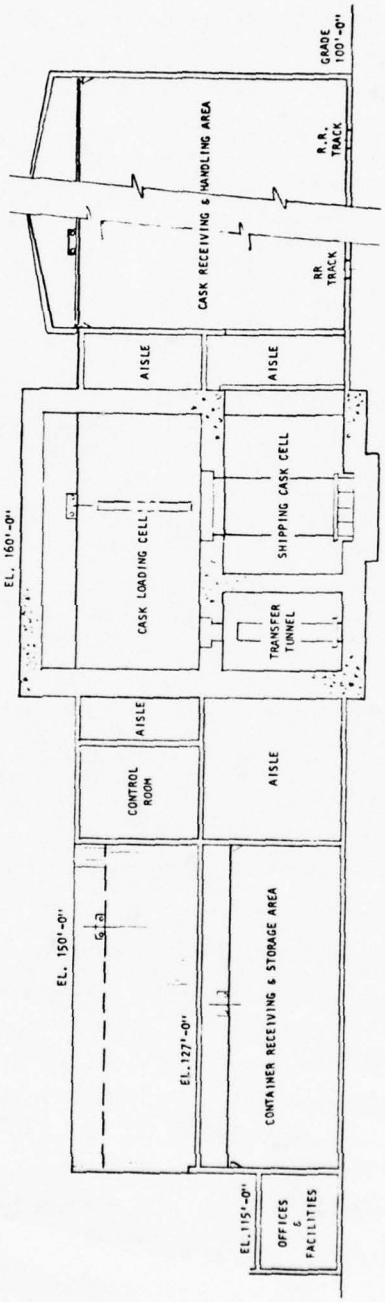


FIGURE 5.7.46. SFPF Container Receiving and Offsite Loadout Area, Section E-E -E

Fuel Drying. Figure 5.7.47 is a flow diagram for the spent fuel assembly drying system used in the failed and unfailed fuel cells. Each unfailed fuel cell contains 5 PWR and 7 BWR drying wells which are grouped into three drying circuits. The failed fuel cell contains one PWR and one BWR drying well and a single drying circuit. The contaminated condensate from the failed fuel cell is collected and pumped to the filter-deionizer system and used as storage pool water in the modified ISFSF.

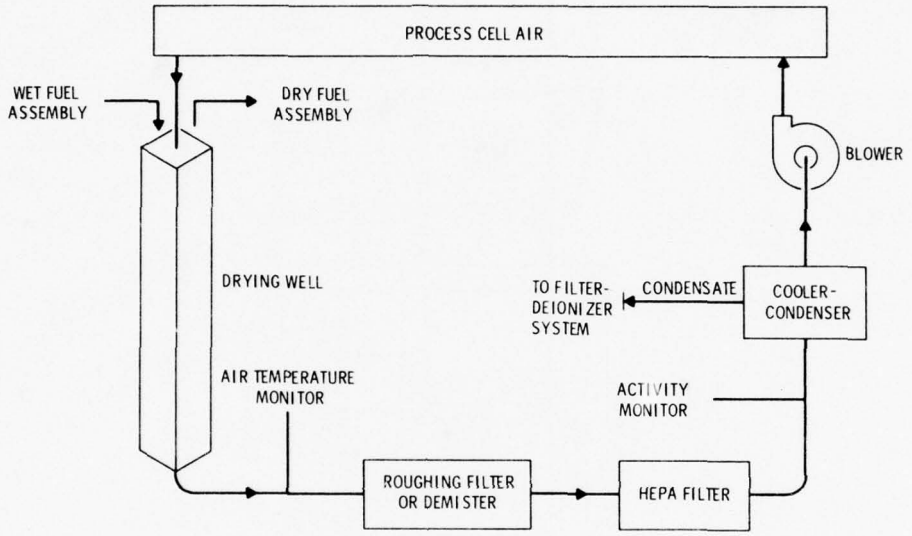


FIGURE 5.7.47. Fuel Drying Air Circulation System

Package Holding and Testing. Fifty wells or sleeves each hold a canister or overpack. A remotely operated leak detector, that has helium gas and fission activity probes is mounted on a bridge crane. This crane, which moves on rails, can be positioned at each well location to test for leaking canisters or overpacks. Fresh air blowers that circulate the test air are in an adjacent machinery area.

Offsite Loadout. Packaged spent fuel is moved from the holding and testing cell through the air tunnel on a motorized cart. A bridge crane in the cask loading cell is used to pick the packaged fuel out of the transfer cart, lift it into the cell, and load it into the shipping cask. The cask cover is removed into the loading cell, and the top of the cask is sealed against the floor. These activities are all performed remotely. After the shipping cask is loaded, the shielding cover is put in place and the shipping cask is then moved to the cask receiving and handling area. After the cover has been secured, the cask is tilted to a horizontal position and placed onto the rail car or truck with the 125-ton bridge crane.

Container Receiving. An overhead bridge crane serves the washing and drying area, the inspection area, the leak-test and labeling area, the repair area (if required), and the storage areas. Containers are moved out of storage to a loadout area, where they can be picked up by a second bridge crane and placed on a cart for transfer to the fuel packaging areas.

Ventilation System: Process Areas. The ventilation system draws outside air into the canister preparation and temporary storage areas and other normally uncontaminated areas. The air then blows through HEPA filters to potentially contaminated areas, through the shielded cells, and through the final filter stages and the exhaust blowers before stack discharge to the atmosphere. Air from the failed fuel cell passes through an additional stage of HEPA filtration before joining the ventilation air from the other cells.

Additional outside filtered air in the hold and test cell provides for the final leakage check of the packaged canisters. This test air discharges into the cell and mixes with the cell ventilation air. The ventilation of the cask loading area is independent of the packaging facility ventilation.

Ventilation System: Personnel Areas. Personnel areas such as operating areas, control room, lunch and locker rooms, and offices are air conditioned, with 80% recirculation.

Shielding and Remote Handling Equipment. All operations for handling the fuel are performed in shielded reinforced concrete cells using cranes, manipulators, or carts. Cell operations are observed through shielded glass windows with at least the equivalent shielding thickness as the cell walls.

Carts, which are on rails, move canisters and spent fuel between the cells through a tunnel below the cells. Cart access is through a normally covered port. Using a mirror and cell window for guidance, operators handle canisters or spent fuel through the port with a crane hook.

The crane moves material within the cells. Some operations and maintenance tasks such as placement of caps on the canisters, canister welding, and helium filling are performed using special equipment or manipulators.

5.7.3.5 Spent Fuel Packaging Facility Operating and Maintenance Requirements

The facility operates continuously 24 hours a day, 7 days a week. All components are operated 24 hours a day except for the packaging of failed fuel assemblies and the receiving of canisters and overpacks, which may be performed on a normal day shift. Annual throughput of the SFPF is 6720 assemblies (2690 PWR assemblies and 4030 BWR assemblies) or ~23 assemblies/day, assuming 300 days/yr operation. Two to three failed assemblies/wk will be processed if it is assumed that 2% of the assemblies have failed rods. Process area capacity of the SFPF is large enough that a maintenance outage in any area does not stop the entire operation. The following arrangement should provide adequate capacity:

Facility or Operation	Number of Cells	Number of Units/Cell
Failed Fuel Packaging	1	1
Unfailed Fuel Packaging	2	
Drying Wells		5 PWR, 7 BWR
Canister Loading Racks		5 PWR, 7 BWR
Welding and Helium Addition System		2
Holding and Testing	1	50

Operating and Maintenance Methods. All fuel handling and process operations are remotely performed using cranes, carts, manipulators, and special devices. Packaging cells are maintained remotely because nuisance contamination makes decontamination of equipment impractical each time there is an equipment failure. Maintenance in other areas where fuel canisters and associated nuisance contamination are not present is performed by contact methods.

Staffing. Estimated staffing requirements for spent fuel packaging and transfer to an onsite storage facility are shown in Table 5.7.27. Because spent fuel packaging and package shipment offsite for storage are an alternative scheme, the estimated staffing requirements for these operations are presented in Table 5.7.28.

TABLE 5.7.27. Fuel Packaging Facility Staffing Requirements for Onsite Storage

Job Description	Personnel Required, man-yr/yr
Operators	25
Maintenance	7
Radiation monitors	5

TABLE 5.7.28. Fuel Packaging Facility Staffing Requirements for Offsite Storage

Job Description	Personnel Required, man-yr/yr
Operators	52
Maintenance	16
Radiation monitors	10

Supplies and Utilities. Table 5.7.29 shows supply requirements for facility operations using both onsite and offsite storage modes. Tables 5.7.30 and 5.7.31 give the utility requirements for plant operations using onsite storage and offsite storage, respectively.

Hazardous Materials. Small quantities of decontaminating agents are used in the reference facility including detergent, organics, and nitric acid. These materials are handled according to safe industrial practices and present minimal hazards.

TABLE 5.7.29. Spent Fuel Packaging Facility Supply Requirements for Onsite or Offsite Storage

Material	Use	Annual Requirement
Detergent		
SP-210[a]	Decontamination of canisters	13 m^3
Powdered	Cleaning	0.13 m^3
Helium	Fill canisters	1.1×10^3 m^3
Canisters	Fuel containment	
PWR		2690
BWR		4030
Overpacks	Additional containment for canisters that contain failed fuel	
PWR		55
BWR		80

a. SP-210 is a decontamination agent of a proprietary composition containing detergent, wetting, and rinsing agents. It is used as a 10% wt solution in water. The decontamination solution has a pH of 10.9 and a specific gravity of 1.05.

TABLE 5.7.30. Spent Fuel Packaging Facility Utility Requirements for Onsite Storage

Utility	Use Rate	Annual Requirement
Electricity	900 kW	7.9×10^6 kWh
Water (Process)	7 m^3/day	2,600 m^3
Steam (Heating)	7.4×10^4 kg/day	2.7×10^7 kg
Coal	1.1×10^4 kg/day	4×10^6 kg

TABLE 5.7.31. Spent Fuel Packaging Facility Utility Requirements for Offsite Storage

Utility	Use Rate	Annual Requirement
Electricity	1000 kW	8.8×10^6 kWh
Water (Process)	8 m^3/day	2900 m^3
Steam (Heating and Other)	8.2×10^4 kg/day	3×10^7 kg
Coal	1.1×10^4 kg/day	4×10^6 kg

5.7.3.6 Secondary Wastes From the Spent Fuel Packaging Facility

Secondary wastes generated from facility operation for the two storage options of moving packaged spent fuel to onsite storage or shipping it to offsite storage are shown in Tables 5.7.32 and 5.7.33.

TABLE 5.7.32. Secondary Wastes for the Fuel Packaging Facility for Onsite Storage

Description	Volume, m^3/yr	Radioactivity Factors[a] Activation Products	Fission Products	Actinides
Combustible and compactable waste	500	All 1×10^{-7}	All 1×10^{-9}	0
Wet wastes	20	All 1×10^{-5}	Cs 4×10^{-6} All others 1×10^{-7}	0
Failed equipment and noncombustible waste	55	All 1×10^{-8}	All 1×10^{-10}	0

a. Fraction of input activity in secondary wastes. For input use column 3 of Table 5.7.2 and 2000 MTHM/yr.

TABLE 5.7.33. Secondary Wastes for the Fuel Packaging Facility for Offsite Storage

Description	Volume, m^3/yr	Radioactivity Factors[a] Activation Products	Fission Products	Actinides
Combustible and compactable waste	550	All 1×10^{-7}	All 1×10^{-9}	0
Wet wastes	20	All 1×10^{-5}	Cs 4×10^{-6} All others 1×10^{-7}	0
Failed equipment and noncombustible waste	60	All 1×10^{-8}	All 1×10^{-10}	0

a. Fraction of input activity in secondary wastes. For input use column 3 of Table 5.7.2 and 2000 MTHM/yr.

5.7.3.7 Emissions From the Spent Fuel Packaging Facility

Emissions from the packaging facility operation for the two storage options of moving pacakaged spent fuel to onsite storage or shipping it to offsite storage are shown in Tables 5.7.34 and 5.7.35. The radionuclide release estimates are the same for the two options and are based on the following estimates and assumptions:

- The releases from the fuel rods of all fission products and activation products are the same as in the receiving portion of the water basin storage of unpackaged spent fuel case (Section 5.7.1).
- 100% of the ^{3}H, ^{14}C, ^{85}Kr, and ^{129}I released from the rods is released to the atmosphere.

- 50% of the other fission products and the activation products released from the rods remains as dry material (the release of which is limited to $<1 \times 10^{-7}$ by HEPA filters) and 50% is ultimately sent to the waste evaporator, where 10^{-5} of that 50% is released to the atmosphere with the vaporized excess water.

TABLE 5.7.34. Emissions from the Facility for Packaging Spent Fuel for Onsite Storage

Emissions	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere[a]
Gaseous	Facility air and vaporized excess water	1.4×10^9 m^3	^{3}H = 2×10^{-6} ^{14}C = 6×10^{-6} ^{85}Kr = 6×10^{-5} ^{129}I = 2×10^{-5} Cs = 4×10^{-11} Other FP = 1×10^{-12} Actinides = negligible Activation products = 1×10^{-10}
	Minor accident integrated annual release		None identified
Other	Heat	7.8×10^3 MW-hr (2.7×10^{10} BTU)	

a. Fraction of input activity (Table 5.7.2) released to atmosphere. Use 6.5 year age. Includes DFs in process concentrator where applicable. Release assumed to be uniform over the year.

TABLE 5.7.35. Emissions from the Facility for Packaging Spent Fuel for Offsite Storage

Emissions	Description	Annual Quantity	Radioactivity Release Factor to Atmosphere[a]
Gaseous	Facility air and vaporized excess water	1.4×10^9 m^3	^{3}H = 2×10^{-6} ^{14}C = 6×10^{-6} ^{85}Kr = 6×10^{-5} ^{129}I = 2×10^{-5} Cs = 4×10^{-11} Other FP = 1×10^{-12} Actinides = negligible Activation products = 1×10^{-10}
	Minor accident integrated annual release		None identified
Other	Heat	9.0×10^3 MW-hr (3.0×10^{10} BTU)	

a. Fraction of input activity (Table 5.7.2) released to atmosphere. Use 6.5 year age. Includes DFs in process concentrator where applicable. Release assumed to be uniform over the year.

5.7.3.8 Spent Fuel Packaging Facility Decommissioning Considerations

The SFPF is designed for a useful operating life of 30 years. At the end of the operating life of the facility, structural materials and associated equipment are expected to be contaminated with about 10 Ci of mixed fission products. Equipment and systems are designed to facilitate the decontamination and decommissioning of these materials.

Monitoring and recording equipment are incorporated in the facility design to assess contamination levels. Facility materials and equipment are selected for their ease of ultimate retirement and removal. Facility structure surfaces that are highly susceptible to significant radionuclide contamination that would be difficult to remove are covered with a removable surface.

5.7.3.9 Spent Fuel Packaging Facility Postulated Accidents

The facility has highly reliable and redundant, normal and emergency cooling, atmospheric protection, and containment systems. Postulated minor, moderate, and severe accident scenarios for the reference spent fuel packaging facility are given in Tables 5.7.36, 5.7.37 and 5.7.38.

TABLE 5.7.36. Spent Fuel Packaging Minor Accidents

Accident No. and Description	Sequence of Events	Safety System	Release
5.7.15 – Loss of normal electrical power; expected frequency 0.175/yr.	1. Power to substation supplying packaging facility interrupted. 2. Emergency power supplied to facility.	1. Emergency diesel generator.	None
5.7.16 – Loss of normal cooling air supply; expected frequency 0.025/yr.	1. Primary air cooling system fails. 2. Fuel in drying wells, welding station, or holding area begins to heat up. 3. Emergency cooling system starts up. 4. Temperatures are reduced to normal.	1. Redundant temperature sensors and alarms 2. Back-up cooling system.	None
5.7.17 – Equipment failure - fuel element suspended in air; expected frequency 0.25/yr.	1. Temperature of fuel increases; natural convection provides some cooling. 2. If fuel temperature exceeds a specific limit, spray cooling is provided to prevent fuel damage. 3. Equipment is remotely repaired.	1. Fuel element temperature sensors. 2. Water spray system. 3. Remote repair capabilities.	None

For purposes of environmental consequence analysis, the material releases associated with accident numbers 5.7.18 and 5.7.20 in Tables 5.7.37 and 5.7.38 have been selected as umbrella source terms. (The concept of an umbrella source term is explained in Section 3.7.) This means that the releases from these accidents are the largest in their respective source term categories. The environmental consequences of these accidents are described in DOE/ET-0029.

Accidents are cross indexed with their appropriate umbrella source terms in Appendix 3A, Section 3.

TABLE 5.7.37. Spent Fuel Packaging Moderate Accidents

Accident No. and Description	Sequence of Events	Safety System	Release
5.7.18 — Fuel handling accident; expected frequency 1.3/yr.	1. Cladding ruptured in a 0.46 MTHM PWR assembly through mishandling; approximately 1% of the rods fail. 2. Mixed fission products and fission gases are released to the cell. 3. Element packaged as failed fuel (canister and overpack).	1. Operators trained for safe equipment operation. 2. Off-gas system equipped to remove particles. 3. Failed fuel packaging system available.	Release in 15 min via the facility stack (based on 6.5 yr old fuel) includes: $^{3}H = 1.4 \times 10^{-2}$ Ci $^{14}C = 1.0 \times 10^{-4}$ Ci $^{85}Kr = 9.0$ Ci $^{129}I = 1.5 \times 10^{-5}$ Ci Cs = 8.3×10^{-10} Ci Other FP = 7.4×10^{-10} Ci Actinides = 4.1×10^{-10} Activation products = 1.6×10^{-11} Ci
5.7.19 — Shipping cask dropped into cask well; expected frequency 0.01/yr.	1. Equipment failure or operator error causes cask to drop into cask well. 2. Shipping cask inspected for damage. Cask expected to be undamaged. 3. Impact absorber removed and repaired if damaged.	1. Impact absorber minimizes cask damage.	None

TABLE 5.7.38. Spent Fuel Packaging Severe Accidents

Accident No. and Description	Sequence of Events	Safety System	Release
5.7.20 — Dropped fuel assemblies; expected frequency 0.01/yr.	1. PWR assembly (0.46 MTHM) dropped to floor due to operator error or equipment failure; 20% of the fuel rods rupture. 2. Fission products released to cell. 3. Fuel element removed and packaged as failed fuel (canister and overpack).	1. Operators trained in safe equipment operation. 2. Filtration of cell air for removal of particles.	Release in 15 min to the atmosphere via the facility stack (based on 6.5 yr old fuel) includes: $^{3}H = 2.8 \times 10^{-1}$ Ci $^{14}C = 2.0 \times 10^{-3}$ Ci $^{85}Kr = 180$ Ci $^{129}I = 3.0 \times 10^{-4}$ Ci Cs = 1.7×10^{-8} Ci Other FP = 1.5×10^{-8} Ci Actinides = 8.2×10^{-9} Ci Activation products = 3.2×10^{-10} Ci

5.7.3.10 Spent Fuel Packaging Facility Costs

Estimates are made, in mid-yr 1976 dollars, of capital, operating, and levelized unit costs. A description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

Capital Costs. The capital cost estimate for the spent fuel packaging facility is shown in Table 5.7.39. It is assumed that the SFPF is built after the adjacent modified ISFSF has been operating a number of years. However, the modified ISFSF is built to accommodate the addition of the SFPF with simple tie-ins and without major shutdowns or renovation.

TABLE 5.7.39. Spent Fuel Packaging Facility Capital Cost Estimate

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		60	10,300	1,000	11,300
Buildings and structures		1,800	8,100	21,600	29,700
Bulk materials		190	4,300	2,300	6,600
Site improvements		50	100	600	700
Subtotal of direct site construction costs		2,100	22,800	25,500	48,300
Indirect site construction costs	560	420	9,300	12,400	21,700
Total field cost	560	2,520	32,100	37,900	70,000
Architect-engineer services					14,000
Subtotal					84,000
Owner's cost					25,000
Total facility cost					109,000
Estimated accuracy range					±30%

The estimate covers all capital costs directly resulting from the addition of the SFPF as an integral part of the storage facility. The costs also include the effect of tie-ins to the water basin storage areas and incremental additions for the storage facility utilities including electricity, compressed air, and water which are supplied to the SFPF. Storage facility general costs are not allocated to the SFPF for such services as laboratories, warehouses, administration office, vehicle repair shops, etc.

Capital costs includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation with the exception of working capital. The costs of facilities for handling and disposing of secondary nuclear wastes, such as spent filters or failed contaminated equipment, and for spent fuel cask unloading are included in the costs of the adjacent storage facility.

The costs for the canister and overpack containers are included in the operating cost estimate. The costs for shipping casks which are primarily intended for use offsite are not included in the SFPF costs, but are included in transportation costs.

Operating Cost. The annual operating cost for a 2000 MTHM/yr fuel packaging facility is shown in Table 5.7.40. Direct labor costs are based on manpower estimates given in Table 5.7.27. Process material costs consist of 2690 carbon steel PWR canisters at $1,600 each, 4030 carbon steel BWR canisters at $1,100 each, 55 PWR canister overpacks at $1,800 each and 80 BWR canister overpacks at $1,300 each. Utility costs are derived from requirements shown in Table 5.7.30. Annual maintenance materials costs are estimated using the standard method described in Section 3.8.

TABLE 5.7.40. Fuel Packaging Facility Operating Cost Estimate

Cost Element	Annual Costs, $1000s
Direct labor	600
Process materials	8,900
Utilities	200
Maintenance materials	450
Overhead	900
Miscellaneous	350
Total	11,400
Estimate accuracy range	±25%

Operating costs exclude costs for treatment of secondary wastes. These are included in the costs of secondary waste treatment at the adjacent storage facility. The estimates for the miscellaneous items are intended to include all unidentified operating costs. The costs of taxes, insurance, and interest are included in the capital charge segment of the levelized unit cost.

Levelized Unit Cost. Table 5.7.41 lists the total levelized unit cost as well as the levelized capital and operating components. Unit costs of modifications to a contiguous water basin storage facility to service the packaging facility developed in Section 5.7.2 are also included in the unit cost totals for the packaging facility. Cost estimates are developed for both private ownership and federal government ownership.

TABLE 5.7.41. Spent Fuel Packaging Facility Levelized Operating Cost Estimate

Cost Element	Unit Cost, $/kgHM	
	Private Ownership	Federal Ownership
Levelized capital charge	13.50	6.80
Levelized operating charge	5.80	5.80
Incremental unit cost of modified water basin to service the packaging facility (see 5.7.2.9)	6.00	3.00
Total levelized unit cost	25.30	15.60
Estimate accuracy range	±30%	±25%

The operating scenario assumes a 2-yr startup period with the facility operating at one-third capacity the first year and two-thirds capacity in the second year. The facility operates 13 more years at full capacity and then is decommissioned. Unit costs would change only slightly for longer operating periods. Private operation would cost about $10 more per kg or 70% more than Federal operation due to tax payments and higher costs of capital.

Reference facility design for packaging and storage facilities uses rectangular canisters and overpacks. If round canisters were used, the per canister costs would drop about 27% or $2.3 million annually, decreasing the unit cost by approximately $1/kg heavy metal. However, if round canisters were used the facility configurations would change substantially. Storage volume requirements and capital costs would probably increase. Also, fewer packaged fuel canisters could be transported in a spent fuel cask, thus increasing the unit packaged spent-fuel transportation cost.

5.7.3.11 Construction Requirements for the Spent Fuel Packaging Facility

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating this impact.

Project Schedules and Construction Manpower. The estimated engineering, procurement and construction schedule for the SFPF is shown in Figure 5.7.48. The construction labor force size, composition, and schedule is shown on Figure 5.7.49.

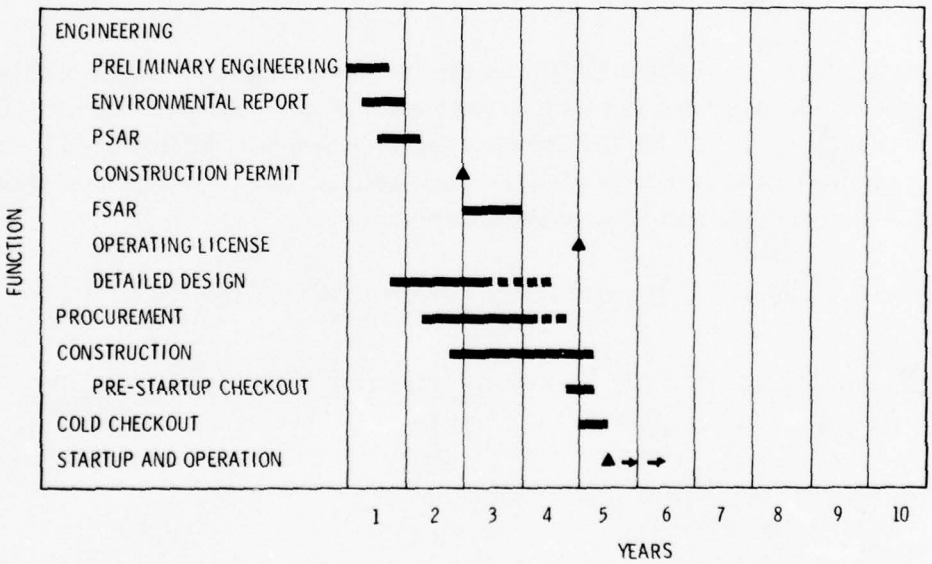


FIGURE 5.7.48. Spent Fuel Packaging Facility Engineering, Procurement and Construction Schedule

Distribution Between Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the SFPF. Offsite costs are those for all offsite services, offsite equipment fabrication and/or assembly, and material purchased elsewhere. The distribution of total costs in these categories is shown below:

	Costs, $1000s
Onsite	43,000
Offsite	66,000
Total	109,000

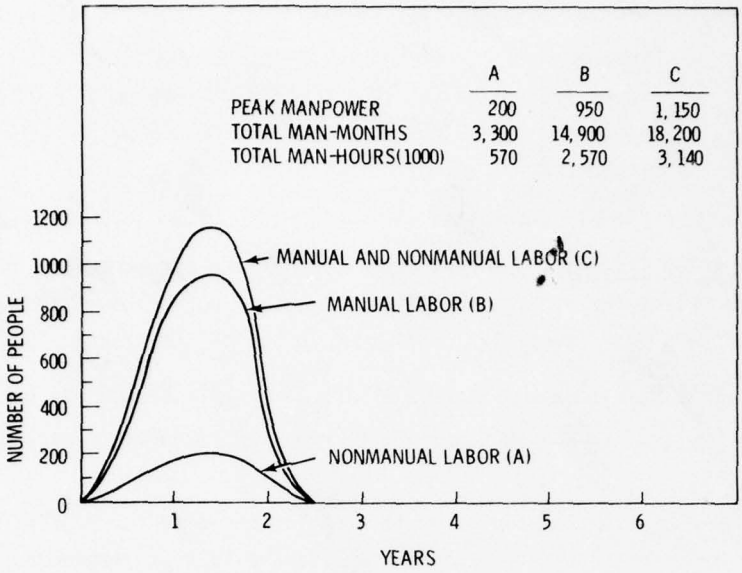


FIGURE 4.7.49. Spent Fuel Packaging Facility Construction Labor Force Schedule

Site Requirements. The major siting restriction is that the reference facility must not be located on a flood plain. Requirements for the facility location include:

- access to supply of water,
- access to rail and highway,
- access to moderate supply of electrical power, and
- minimum conflict with other beneficial land uses.

The SFPF, built next to the modified unpackaged spent fuel storage facility, requires additional access roads, parking areas and a rail spur inside the storage facility area. An additional 4 ha (10 acres) are required at the storage facility, plus an area of 1.6 ha (4 acres) adjacent to the SFPF for construction storage, work yards, temporary buildings, and labor parking. This requirement does not include an area for onsite storage of the packaged fuel.

Land commitments for the SFPF are included with those of the modified unpackaged spent fuel storage facility (see Section 5.7.2.11).

Water. Approximately 42,000 m^3 (11 x 10^6 gallons) of water are required during construction.

Construction Materials. Major material requirements for facility construction are:

Concrete	23,000 m^3	(30,000 yd^3)
Steel	4,500 MT	(5,000 tons)
Copper	18 MT	(20 tons)
Zinc	4.5 MT	(5 tons)
Lumber	1,900 m^3	(800 MFBM)

Energy. Resources used during construction are:

Propane	380 m^3	(100,000 gal)
Diesel fuel	3,800 m^3	(1,000,000 gal)
Gasoline	2,650 m^3	(700,000 gal)
Electricity		
Peak demand		1,300 kW
Total consumption		1,800,000 kWh

Transportation Requirements. The railroad track to the packaged fuel offsite shipping facility is a branch from the storage facility main spur. No separate transportation requirements for the SFPF have been identified other than those for the storage facility.

5.7.3.12 Effects of Fuel Cycle Options on the Spent Fuel Packaging Facility

Once-Through Cycle. For this option, a SFPF would be required to package fuel for final isolation.

Uranium and/or Plutonium Recycle. For this option the need for a SFPF, depends on when the spent fuel is reprocessed. Facilities may not be available to reprocess the fuel, or a decision to reprocess the spent fuel may be delayed, which would require spent fuel storage until these situations are resolved. In this event, if a long storage period is foreseen, it might prove desirable to encapsulate the spent fuel for the extended storage period.

5.7.4. Independent Packaged Spent Fuel Receiving Facility

As an alternative to storing packaged spent fuel on the same site as the packaging facility, the packaged spent fuel storage could be located at a separate site. This could permit the packaging of spent fuel as a private competitive venture while the storage would be confined to a government reservation. Also, it might be desirable to provide storage at more than one site. In either case a separate packaged spent fuel receiving facility would be required at the separate storage site. This section describes such a receiving facility.

The independent packaged spent fuel receiving facility receives packaged spent fuel from an offsite spent fuel packaging facility for transfer to an adjacent storage facility. The facility can also receive packaged spent fuel from the adjacent storage area for offsite shipment or for overpacking a failed package. Packaged spent fuel storage facilities which could be coupled to the receiving facility include water basin, air-cooled vault, dry caisson, or surface cask facilities, described in Sections 5.7.5 to 5.7.8.

Receiving and handling of packaged spent fuel is similar to receiving and handling packaged solidified high-level waste (SHLW) shipments (Section 5.4.2), and the facility design uses similar structures and operating methods. Information from the design of a retrievable surface storage receiving facility for SHLW was used as a basis.[17] Although a receiving facility like this has never been operated, the design incorporates tested techniques that have been used at nuclear power plants and reprocessing plants for spent fuel receiving and shipping.

5.7.4.1 Alternatives for the Independent Packaged Spent Fuel Receiving Facility

There are two principal alternatives for a packaged fuel receiving facility (PFRF): dry receiving and handling, and wet receiving and handling. Dry receiving and handling was selected for the following reasons:

- reduced cask and container radioactivity-contamination potential (In a water basin, unloading a leaking fuel package could contaminate both the inside and outside of the transport cask. Also, the basin water may be contaminated with nuisance concentrations of radionuclides which might contaminate the fuel container or the cask. On the other hand, with dry unloading those sources of contamination are virtually eliminated.)
- elimination of water treatment operations
- less waste generation
- simplified operations
- lower costs

5.7.4.2 Design Basis for the Independent Packaged Spent Fuel Receiving Facility

The following design assumptions were made for the reference facility:

- The facility is adjacent to a spent fuel storage facility and is located at an independent site away from a spent fuel packaging facility.
- The packaged fuel, which is aged at least 6.5 years after nuclear power plant discharge, is received at a rate of 2000 MTHM/yr.
- The packaged fuel is dry handled in hot cells.
- Hot cell ventilation air is filtered before release to the atmosphere.
- Fuel package inspection, decontamination, and overpacking capabilities are provided.
- Overpacking capability is provided for up to 2% of total packages received.
- The receiving facility houses support facilities (utilities supply, change and lunch rooms, warehousing, laboratories, administration office, maintenance shops, etc.) for the adjacent storage facility.
- Detection systems are provided to aid in minimizing any discharge of radioactive material.

5.7.4.3 Operations for the Independent Packaged Spent Fuel Receiving Facility

When the rail shipping cask arrives at the reference facility, the exterior of the rail car and cask are washed to remove material accumulated during transport. Tiedowns, protective equipment, and cooling systems are removed from the cask. After the cask is monitored for radionuclide contamination, a bridge crane moves the cask from the rail car to the unloading cell transfer aisle or to the decontamination pit for exterior radionuclide removal. Contamination is unlikely because the cask exterior is cleaned before leaving the packaging facility, the spent fuel assemblies are packaged, and the casks are used only for transporting packaged spent fuel.

The cask is lowered into a transfer aisle where it is positioned with a transfer cart under the receiving and transfer cell where it is then connected to a cask hatch. Next a cell crane removes the cask lid (the head bolts are removed in cask preparation), picks up the spent fuel packages, and deposits the packages at an inspection station. If necessary the packages are decontaminated, lowered to a transfer aisle, delivered by cart to the overpacking cell, overpacked, and returned to the receiving cell. The packages are inserted into storage baskets (water basin storage) or storage racks (dry caisson, surface cask, and air-cooled vault storage) before transfer to the storage facility. Then the packages are transported to the storage facility through either a transfer tunnel or water-filled transfer canal, depending on the storage facility design. Figure 5.7.50 shows a schematic flowsheet for these operations.

Any spent fuel package failures occurring in the receiving or adjacent storage facilities are handled the same way as a failed package discovered at receipt. Any radioactive waste generated at the facility is immobilized, packaged, and shipped offsite. Packaged spent fuel retrieval and shipment is essentially the reverse of fuel receipt.

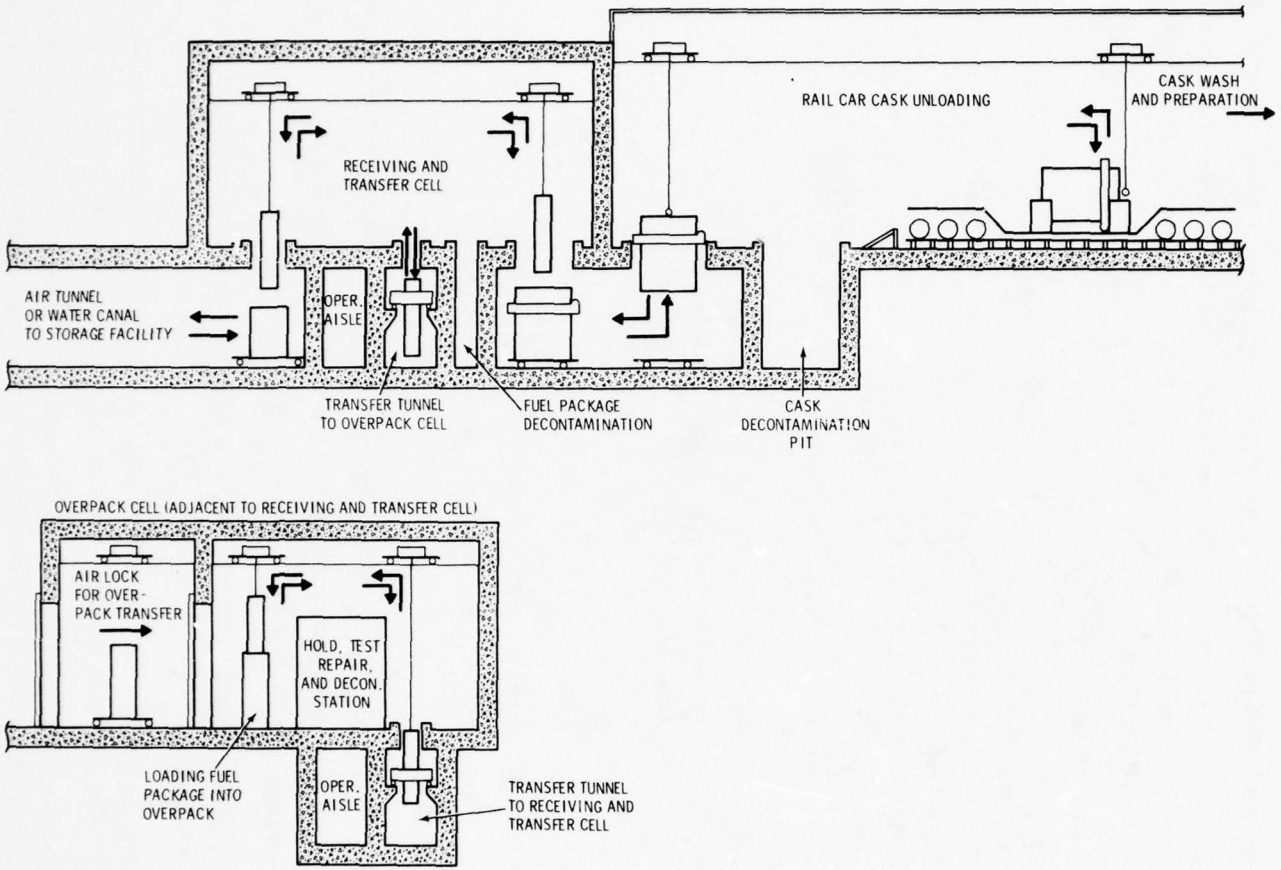


FIGURE 5.7.50. Operations Flowsheet for the Independent Packaged Spent Fuel Receiving Facility

5.7.4.4 Description of the Independent Packaged Spent Fuel Receiving Facility

The reference facility is capable of handling and receiving packaged spent fuel and of providing support facilities, which are shared with an adjacent packaged spent fuel storage facility. The plot plan for receiving and support facilities is shown in Figure 5.7.51.

General Facility Arrangement. Plans and sections of the packaged fuel receiving facilities are shown on Figures 5.7.52, 5.7.53, 5.7.54, and 5.7.55. The support facilities include those facilities listed below:

- process support facilities
  - control room
  - warm maintenance
  - counting room and laboratory
  - aqueous makeup room
  - cell ventilation exhaust filter/fan room
  - cell ventilation stack
- mechanical and electrical rooms (utilities)
  - steam generation
  - compressed air (instrument and utility)
  - water treating (boiler feedwater, process, utility, etc.)
  - emergency electrical (diesel generators)
- water supply wells
- fuel oil storage
- firewater, storage, pumps, and distribution
- sewage treatment and sanitary lagoons
- evaporation ponds
- personnel support facilities (offices, change room, lunch room, health physics, etc.)
- maintenance and repair shops (mechanical, instruments, electrical)
- administration building
- security (guard houses, security fencing, lighting, intruder alarm systems, patrol roads, etc.)

Structures. The rail cask handling gear, which includes the 125-ton bridge crane and its support structure, the cask transfer tunnel, and the cask transfer carriage, are Category I.

Other Category I structures include the spent fuel receiving cell, the overpacking cell, the spent fuel transfer tunnels, the control and operating areas, the cell ventilation filter/fan building. The emergency generator area, the warm maintenance counting room and lab, and the waste handling and treating area are also Category I.

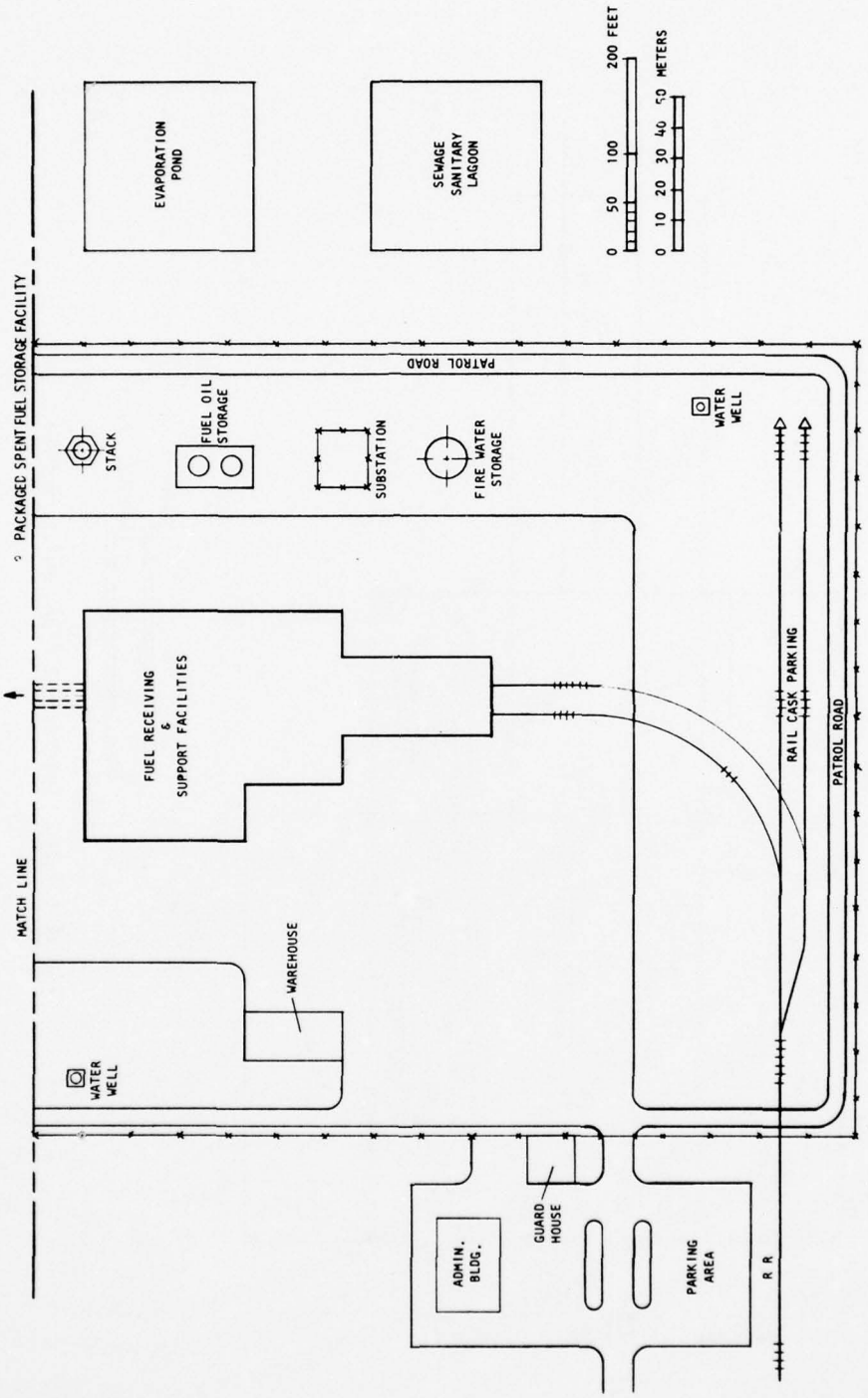


FIGURE 5.7.51. Independent PFRF, Plot Plan

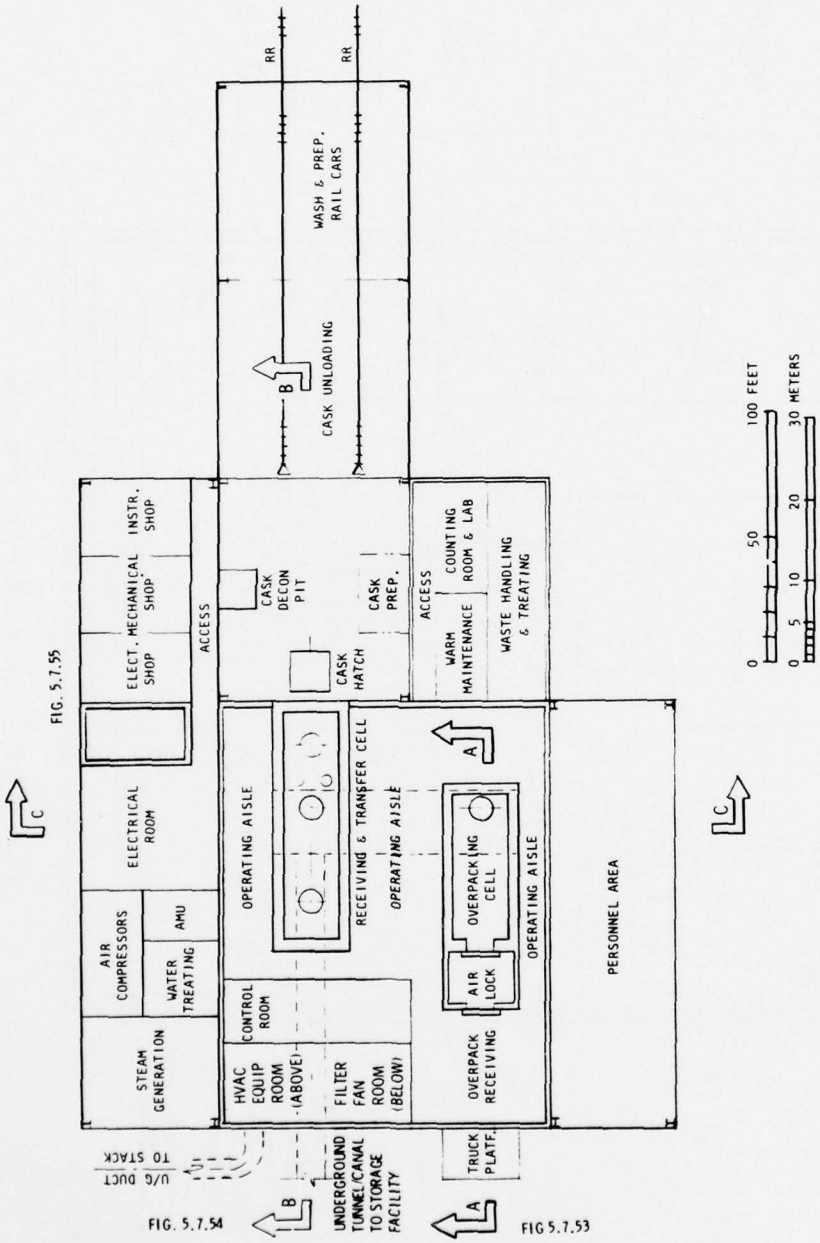
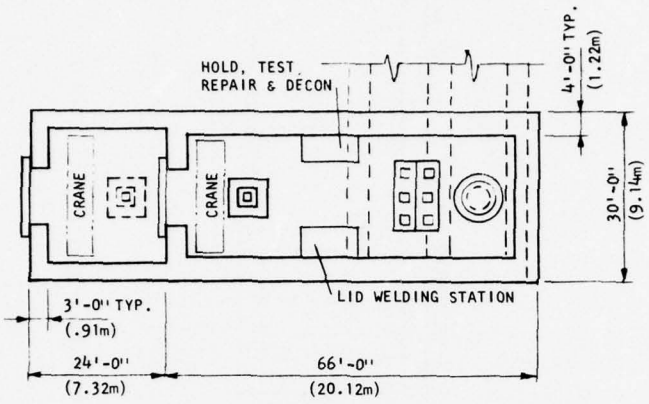
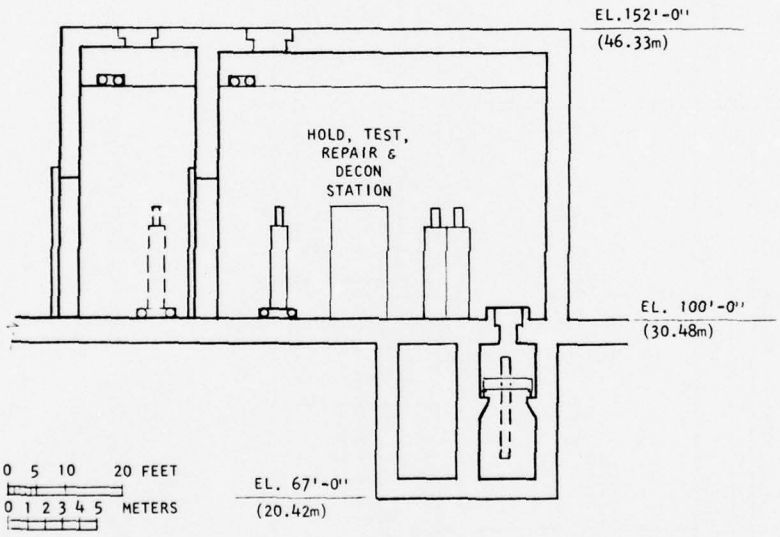


FIGURE 5.7.52. Independent PFRF, Building Plan



Top View



Side View

FIGURE 5.7.53. Independent PFRF, Section A-A Showing Overpacking Cell

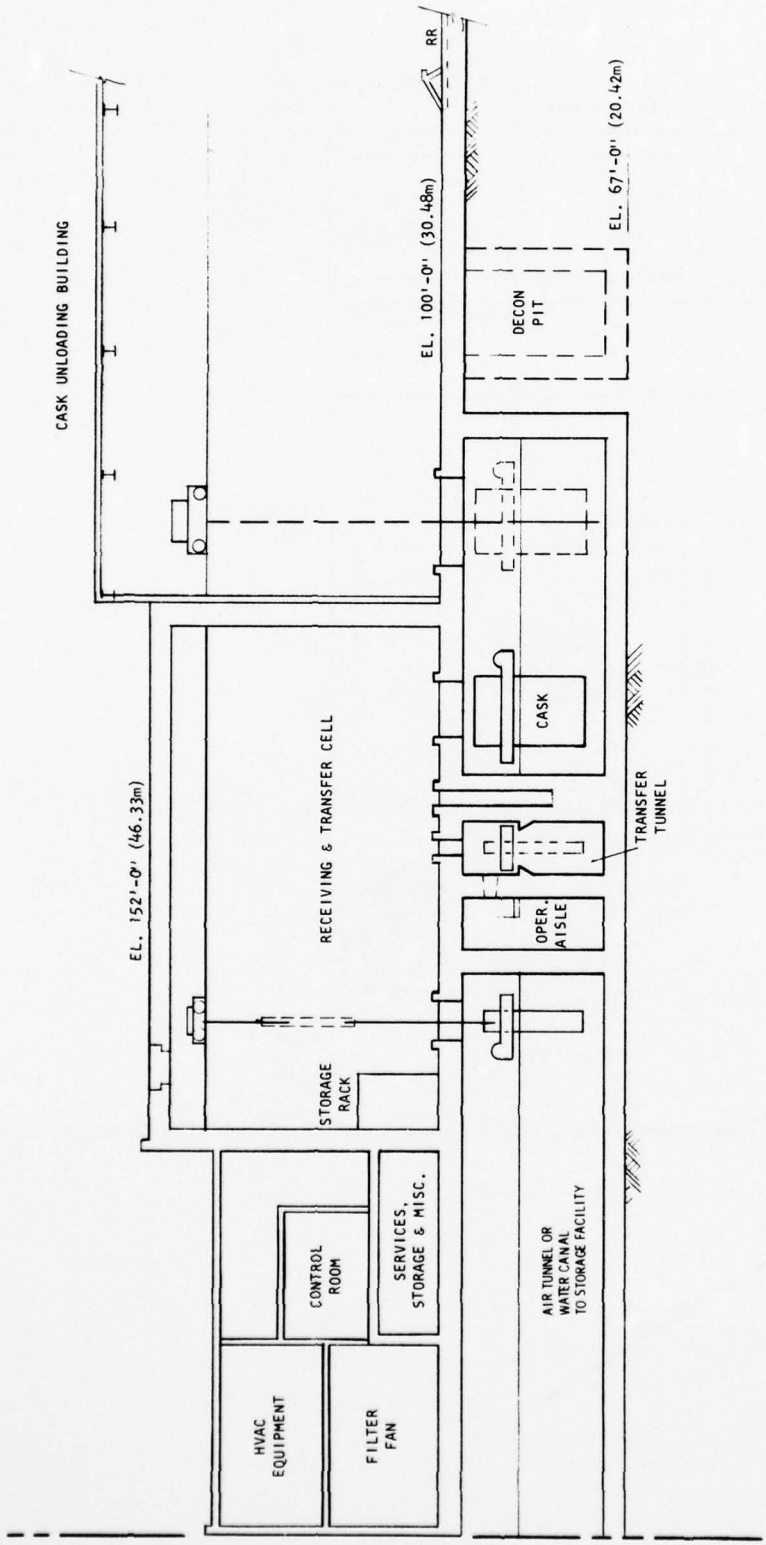


FIGURE 5.7.54. Independent PFRF, Section B-B Showing Receiving and Transfer Facilities

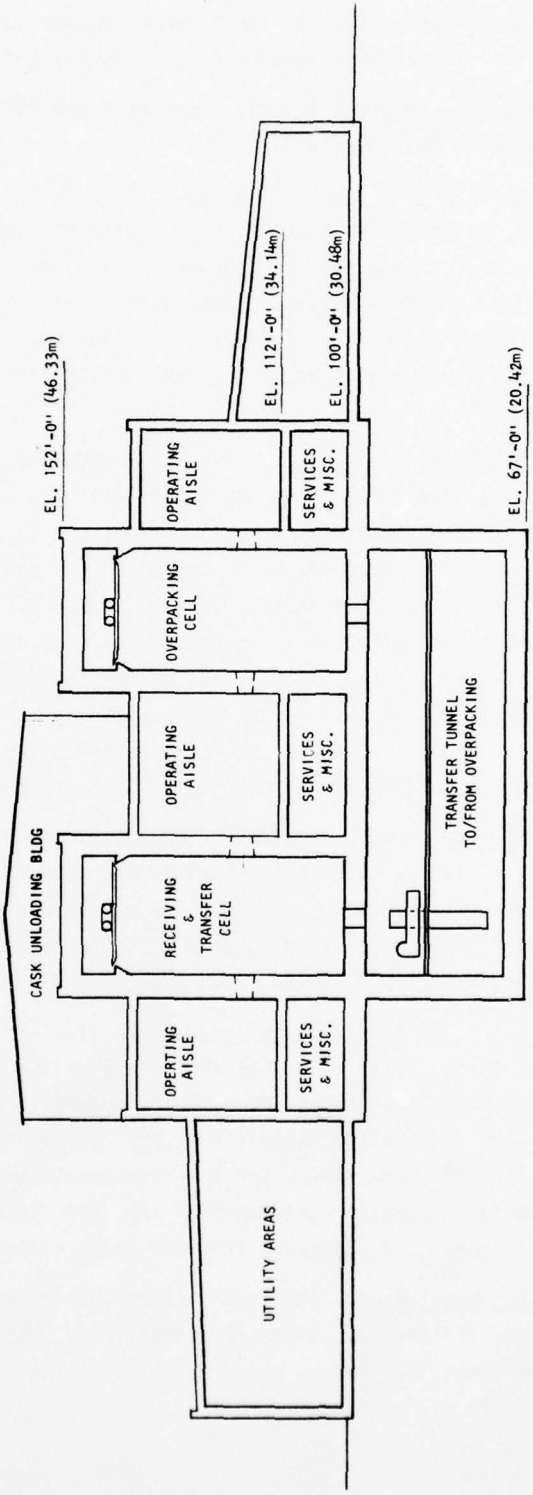


FIGURE 5.7.55. Independent PFRF, Section C-C

The siding and roofing of the cask unloading structure are designed to blow away during a tornado. The balance of the buildings are standard commercial construction, either reinforced concrete or steel framed with insulated metal panels and roof decking.

Systems and Equipment. Systems and equipment provided for the independent packaged spent fuel receiving facilty are described below.

Rail Cask Receiving, Handling and Unloading. Two parallel rail car unloading tracks are served by the 125-ton overhead bridge crane. A separate enclosed area is used for washing incoming cars and for cask accessory gear storage space. The area is designed so that cask cooldown is not required before unloading. Platforms, tools, and other items are provided for unbolting cask heads and for preparing for cask transfer. A motor-driven cask carriage moves the cask between the receiving and overpacking cells through an underground air tunnel, as shown in Figure 5.7.54.

Packaged Spent Fuel Receiving and Transfer. All packaged spent fuel is handled remotely using an overhead bridge crane, power and slave manipulators, and shielded viewing windows. After the cask is sealed to the cask hatch in the floor of the receiving and transfer cell, the cask cover is removed and the spent fuel assemblies are removed one at a time using a remote grapple. Each container is examined visually and by direct contact with absorbent material called swipes to detect possible leakage. Decontamination pits and cooling wells assure complete examination and conditioning before the packaged spent fuel is shipped to the associated storage facility. If overpacking is required, a motorized carrier and transfer tunnels are used to transfer spent fuel containers to the overpacking cell. All packaged spent fuel that proves satisfactory, including some with overpacks, is sent to storage.

Spent Fuel Overpacking. Items used for overpacking operations include the overhead bridge crane, storage racks for the packaged spent fuel, a decontamination station, and remote welding and weld-test equipment. A motorized cart transfers fresh overpacks from an adjacent air lock and supply storage area through a shielding door to a cell. All overpacking is done with the same type of remote equipment used at the spent fuel packaging facility, Section 5.7.3.

Ventilation of Cells and Fuel Transfer Areas. Outside air is drawn through filters and dampers into the cell areas. The cell areas are at a negative pressure with respect to the transfer areas so that air always flows through hatch openings to the area of greater potential contamination. The ventilation exhaust fans draw air from the cell areas through the ventilation filters (roughing and HEPA), and the fans discharge to the stack. Radiation monitors are provided in the system upstream from the HEPA filters. Ventilation system design permits the exhaust filters to be bypassed if there is no contamination in the ventilation air.

Ventilation of Personnel Areas. Personnel areas such as operating areas, control room, lunch and locker rooms, offices, etc., are air conditioned, with 80% recirculation. Shop areas, mechanical and electrical rooms, and similar work areas are ventilated for reasonable comfort but are not fully air conditioned.

Shielding and Handling Requirements. The facility is designed for remote operation. The primary material used for shielding is reinforced concrete. Dose rates to operating personnel are normally <1 mrem/hr. During infrequent maintenance and other activities, dose rates may exceed this level, but the exposure to personnel is kept well within the limits of Title 10, Part 50 of the Code of Federal Regulations.[16]

5.7.4.5 Operating and Maintenance Requirements for the Independent Packaged Spent Fuel Receiving Facility

The receiving facility is designed to operate 24 hr a day, 7 days a week. The cask receiving operation requires four shifts, assuming the turn around time of the rail casks is the same as a spent fuel cask containing unpackaged fuel. Fewer shifts are expected to be needed because the casks should be considerably less contaminated than the unpackaged fuel casks.

All spent fuel handling operations are remotely performed. In facility areas where there is no spent fuel or where the spent fuel can be removed, maintenance operations are done by contact maintenance.

Operating 300 days/yr, the reference facility has a 2000 MTHM/yr capacity for receiving and transferring packaged spent fuel to the associated storage facility. All spent LWR fuel is received in rail casks which transport either 7 packaged PWR fuel assemblies or 17 packaged BWR fuel assemblies. The receiving facility can also overpack up to 2% of the spent fuel packages it receives.

Staffing. Staffing requirements are presented in Table 5.7.42.

TABLE 5.7.42. Independent Packaged Spent Fuel Receiving Facility Staffing Requirements

Job Description	Personnel Required, man-yr/yr
Operators	30
Maintenance	9
Radiation monitors	10

Supplies and Utilities. It is anticipated that no significant amounts of supplies will be used at the facility. Table 5.7.43 presents the utility requirements for reference facility operation.

TABLE 5.7.43. Utility Requirements for the Independent Packaged Spent Fuel Receiving Facility

Utility	Use Rate	Annual Requirement
Electricity	1000 kW	8.8×10^6 kWh
Water	27 m^3/day	1×10^4 m^3
Steam	8×10^4 kg/day	3×10^7 kg
Coal	1.4×10^4 kg/day	5×10^6 kg

Hazardous Materials. No hazardous materials other than the spent fuel are stored or used at the receiving facility. If necessary, some decontaminating agents, such as nitric acid or organics, may be used.

5.7.4.6 Secondary Radioactive Wastes from the Independent Packaged Spent Fuel Receiving Facility

An estimate of the secondary radioactive wastes generated by the reference facility operations is presented in Table 5.7.44.

TABLE 5.7.44. Independent Packaged Spent Fuel Receiving Facility Secondary Radioactive Wastes

Description	Volume, m^3/yr	Radioactivity Factors[a]		
		Activation Products	Fission Products	Actinides
Combustible and compactable waste	120	All 1×10^{-9}	All 1×10^{-11}	0
Wet wastes	5	All 1×10^{-7}	Cs 4×10^{-8} All others 1×10^{-9}	0
Failed equipment and noncombustible waste	10	All 1×10^{-10}	All 1×10^{-12}	

a. Fraction of input activity in secondary wastes. For input use column 3 of Table 5.7.2 and 2000 MTHM/yr.

5.7.4.7 Emissions from the Independent Packaged Spent Fuel Receiving Facility

Estimated emissions from the receiving facility operations are given in Table 5.7.45. Radionuclide releases are assumed to be negligible since the low release rates occurring during packaging operations (Section 5.7.3) would be further reduced by at least several orders of magnitude by storing the fuel elements in high integrity packages.

TABLE 5.7.45. Emissions from the Independent Facility for Receiving Packaged Spent Fuel

Emissions	Description	Annual Quantity	Radioactivity Release to Atmosphere
Gaseous	Facility air and vaporized excess water	3×10^8 m^3	Negligible
	Minor accident integrated annual release		None identified
Other	Heat	9.0×10^3 MW-hr (3.0×10^{10} BTU)	

5.7.4.8 Decommissioning Considerations for the Independent Packaged Spent Fuel Receiving Facility

At the end of the reference facility's life, the projected quantity of residual activity is <0.1 Ci; at least a factor of 10 less than the fuel packaging facility (Section 5.7.3) because that facility handles unpackaged spent fuel assemblies. At the reference receiving facility all spent fuel is packaged, thus reducing radioactivity releases.

The following steps would be taken with respect to decommissioning:

- provide necessary decommissioning equipment and systems
- select appropriate materials of known durability which allow for corrosion, wear, and radiation damage
- coat certain items with removable surfaces
- design for maintenance under operating conditions or for 100-year life
- use a quality assurance program during design, construction, and operation of the facility

5.7.4.9 Postulated Accidents for the Independent Packaged Spent Fuel Receiving Facility

Safe handling of packaged spent fuel is the primary design and operating goal of the receiving facility. This is provided through:

- redundant and highly reliable normal and emergency systems
- highly skilled and trained staff
- Category I structures and equipment

The accidents encountered at this fuel receiving facility would be similar to those of the spent fuel packaging facility (Section 5.7.3.9, Tables 5.7.36, 5.7.37, and 5.7.38). The severe rupture of rods in a packaged fuel element (Table 5.7.38 - Accident 5.7.20) is not considered credible for this operation. The moderate cladding rupture (Table 5.7.37 - Accident 5.7.18) is assumed to occur at 1% of the listed frequency for the packaging facility.

5.7.4.10 Costs for the Independent Packaged Spent Fuel Receiving Facility

Capital, operating, and levelized unit cost estimates have been made in mid-1976 dollars. Cost estimate bases, assumptions, and definitions are described in Section 3.8.

Capital Cost. The capital cost estimate for the independent packaged spent fuel receiving facility is shown in Table 5.7.46. The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation, with the exception of working capital and specific exclusions stated below.

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TABLE 5.7.46. Independent Packaged Spent Fuel Receiving Facility Capital Cost Estimate

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment			3,900	200	4,100
Buildings and structures		1,000	8,000	12,200	20,200
Bulk materials		400	3,700	4,600	8,300
Site improvements		200	1,000	1,800	2,800
Subtotal of direct site construction costs		1,600	16,600	18,800	35,400
Indirect site construction costs	400	300	6,900	9,100	16,000
Total field cost	400	1,900	23,500	27,900	51,400
Architect-engineer services					9,300
Subtotal					60,700
Owner's cost					18,300
Total facility cost					79,000
Estimate accuracy range					±25%

This cost estimate includes only the facilities shown in the plans described in Section 5.7.4.4. Excluded are the effects of incremental additions to utility facilities, which supply electricity, compressed air, steam, and water to the associated spent fuel storage facility. However, this estimate does include the cost of common general services, such as laboratories, warehousing, administration office, repair shops, etc. The interface with the associated storage facility is in the transfer air tunnel or water canal at the match line shown in the plot plan, Figure 5.7.51. The packaged fuel transfer cart is supplied by the storage facility. Costs for containers for overpacking are included in the packaging facility operating cost estimate.

Operating Costs. The operating costs for the independent packaged spent fuel receiving facility are shown in Table 5.7.47. Direct labor costs are based on manpower estimates given in Table 5.7.42. Process material costs are negligible. Utility costs are derived from requirements shown in Table 5.7.43. Annual maintenance materials costs are estimated at 2% of initial major equipment costs. Overhead and miscellaneous costs are estimated by the standard method described in Section 3.8.

Levelized Unit Costs. Table 5.7.48 lists the total levelized unit cost as well as the levelized capital and operating costs. The cost calculations assume Federal ownership of the facility. The operating scenario is based upon the postulated scenarios for filling the packaged fuel storage facilities. First year operation will be at one-third capacity, the second year at two-thirds capacity, followed by 9 years of operation at full capacity (2000 MTHM/yr). For the remaining 10 years before facility decommissioning the receiving facility is used to ship fuel which is removed from the storage facilities.

TABLE 5.7.47. Operating Cost Estimate for the Independent Packaged Spent Fuel Receiving Facility

Cost Element	Annual Costs, $1000s	
Direct labor	900	
Process materials	0	
Utilities	300	
Maintenance materials	100	
Overhead	1100	
Miscellaneous	200	
Total	2600	+50% -25%

TABLE 5.7.48. Independent Packaged Spent Fuel Receiving Facility Levelized Unit Cost Estimate

Cost Element	Unit Cost, $/kg HM	
Levelized capital charge	6.00	
Levelized operating charge	2.10	
Levelized total unit cost	8.10	±30%

5.7.4.11 Construction Requirements for the Independent Packaged Spent Fuel Receiving Facility

Many site preparation and construction factors may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating the reference facility's impact.

Project Schedule and Construction Manpower. The receiving facility is not a complete facility since its construction is always integrated with a particular storage facility (i.e., water basin storage, air-cooled vault storage, storage in dry caissons, or storage in surface casks). The project schedule and construction labor force schedule for the receiving facility is identical to the schedule given in Section 5.7.3.11 for a spent fuel packaging facility. Construction labor man-hour requirements are listed in Table 5.7.46.

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the receiving facility. Offsite costs include all services, equipment fabrication and assembly, and materials purchased elsewhere. The distribution of total costs in these categories is shown below:

	Costs, $1000s
Onsite	30,000
Offsite	49,000
Total	79,000

Site Requirements. The receiving facility is constructed at an independent site. The site should be compatible with storage facility requirements and have access to highway and railroad transportation and to utilities. Approximately 10 ha (25 acres) are required for facility installations. Approximately 3.2 ha (8 acres) are required for construction storage, work yards, temporary buildings, and labor parking. This does not include areas for the associated packaged spent fuel storage facility. A total of 405 ha (1000 acres) is required for the combined facilities' site.

Water. Approximately 30,000 m^3 (8.0×10^6 gal) of water are required during construction.

Construction Materials. Materials committed to facility construction are:

Concrete	16,000 m^3	(21,000 yd^3)
Steel	3,300 MT	(3,600 tons)
Copper	18 MT	(20 tons)
Aluminum	9 MT	(10 tons)
Lumber	940 m^3	(400 MFBM)

Energy. Energy resources used during construction are:

Propane	265 m^3	(70,000 gal)
Diesel fuel	2,600 m^3	(690,000 gal)
Gasoline	1,700 m^3	(460,000 gal)
Electricity:		
Peak demand	680 kW	
Total consumption	1,300,000 kWh	

Transportation Requirements. Approximately 1.6 km (1 mile) of new road are required to provide automobile and truck access from the nearest highway to the site. Approximately 3.2 km (2 miles) of new railroad spur are required for site railroad service.

5.7.4.12 Effects of Fuel Cycle Options

The need for an independent packaged spent fuel receiving facility depends on the requirements for packaging fuel and delivery of that fuel to an independent site. Fuel cycle effects on the need for this facility would be similar to those discussed in Section 5.7.3.12 for the fuel packaging facility.

5.7.5. Water Basin Storage of Packaged Spent Fuel

One alternative for extended storage after packaging the aged spent fuel is water basin storage. The reference facility for this concept is the same type of facility as that described in Section 5.7.1, Water Basin Storage of Unpackaged Spent Fuel, except the pool storage configuration is altered to store more fuel in a single pool. This is believed an acceptable approach because the stored radionuclides and heat generation per MTHM are significantly lower than in the unpackaged spent fuel storage facility. Also, the additional barrier provided by the spent fuel canisters decreases water contaminants, which reduces the amounts of water basin clean-up, radioactive gaseous effluent, and secondary radioactive wastes. The technology for water basin storage of unpackaged spent fuel would be directly applicable to water basin storage of packaged spent fuel.

5.7.5.1 Alternatives for Water Basin Storage of Packaged Spent Fuel

Alternatives for packaged fuel water basin storage are similar to those discussed in Section 5.7.1.1 for unpackaged spent fuel. Neither concrete basin covers nor concrete basin enclosure buildings are considered necessary because the fuel cladding, fuel packages, storage baskets, and basin water serve as the main barriers to release of radioactive material and protect the fuel from physical damage. The emergency system for basin water makeup and the water basins themselves are all Category I structures.

A variation of water basin storage uses concrete for radioactive shielding and water for spent fuel cooling; this method is more aptly termed water-cooled vault storage of packaged spent fuel. It has the disadvantages of both water basin storage (nonpassive cooling system) and air-cooled vault storage (relatively high capital cost). (For more information on air-cooled vault storage see Section 5.7.6.)

An alternative within the concept of water basin storage of packaged spent fuel is to use natural circulation in a completely passive cooling system. However, the facilities to accomplish the required cooling tend to become quite expensive.

5.7.5.2 Design Basis for the Facility for Water Basin Storage of Packaged Spent Fuel

The following assumptions were made in design of the reference water basin storage facility for packaged spent fuel (WBSF-PF):

- The facility receives packaged spent fuel from an adjacent packaging or independent fuel receiving facility through a water-filled tunnel at 2000 MTHM/yr.
- The average exposure of the spent fuel is approximately 29,000 MWD/MTHM and it is aged at least 6.5 years from nuclear power plant discharge.
- Storage can be expanded in 2000 MTHM water basin modules* up to a total of 20,000 MTHM.

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* USNRC Regulatory Guide 3.24 suggests modular construction with storage pool capacity limited to 500 MTHM for storage of unpackaged spent fuel at an independent spent fuel storage facility. In this report, it is assumed that individual pool capacities of 2000 MTHM of packaged fuel are acceptable.

- Each 2000-MTHM water basin module has an initial heat generation rate of 2.7 MW (9.2×10^6 BTU/hr).
- Spent fuel is transferred and stored in baskets holding 4 PWR packages or 9 BWR packages; each package contains a single assembly.
- Special baskets are required for overpacked spent fuel.
- Canister, overpacks, and baskets are of stainless steel.
- In determining critically safe fuel spacing, credit has been taken for neutron absorption in the canisters but not in the storage baskets.
- All spent fuel package handling occurs underwater.
- Each water basin can be isolated from the remaining pools to permit drainage.
- Packaged spent fuel is stored in a single tiered arrangement in a 9 m (30 ft) deep water basin and can be retrieved at any time.
- The facility has air locks and a controlled inleakage of air; incoming air is filtered (roughing filters).
- Conditioning of the air, other than prefiltering, is not required.

5.7.5.3 Operations for the Facility for Water Basin Storage of Packaged Spent Fuel

Spent LWR fuel assemblies, packaged in stainless steel canisters, are received from an adjacent spent fuel packaging facility (SFPF) or an independent packaged fuel receiving facility (PFRF), through a water-filled canal at a rate of 2000 MTHM/yr until the storage pools are full (20,000 MTHM total capacity). If an airborne release of activity should occur, a standby filter system filters the air. Demineralized basin water is circulated within the storage building through a heat exchanger, a filter, and an ion exchanger for removal of heat and radioactive contamination. Cooling towers dissipate the heat to the atmosphere through a secondary cooling water circuit. The storage facility does not use any major chemical processes. Any failed fuel packages are returned to the SFPF or the independent PFRF for repair or overpacking. Fuel is removed from the facility via the water-filled canal and adjacent packaging or receiving facility. Figure 5.7.56 presents a schematic flow diagram of the operation of the reference facility.

5.7.5.4 Description of the Facility for Water Basin Storage of Packaged Spent Fuel

The reference facility for water basin storage of packaged spent fuel consists of 10 modular storage basins. Spent fuel is transferred from an adjacent packaging or packaged fuel receiving facility through a water canal. A plot plan of the facility is shown in Figure 5.7.57.

Figure 5.7.57 shows the reference facility and its cooling towers, control house, ventilation filter/blower building and stack. The common plot, including the reference and adjacent facility, has an outside perimeter road and security fence. The reference storage facility contains a central water canal extending from the adjacent facility. The 10 water storage basins adjoin this canal, five on each side. Packaged spent fuel is moved underwater from the

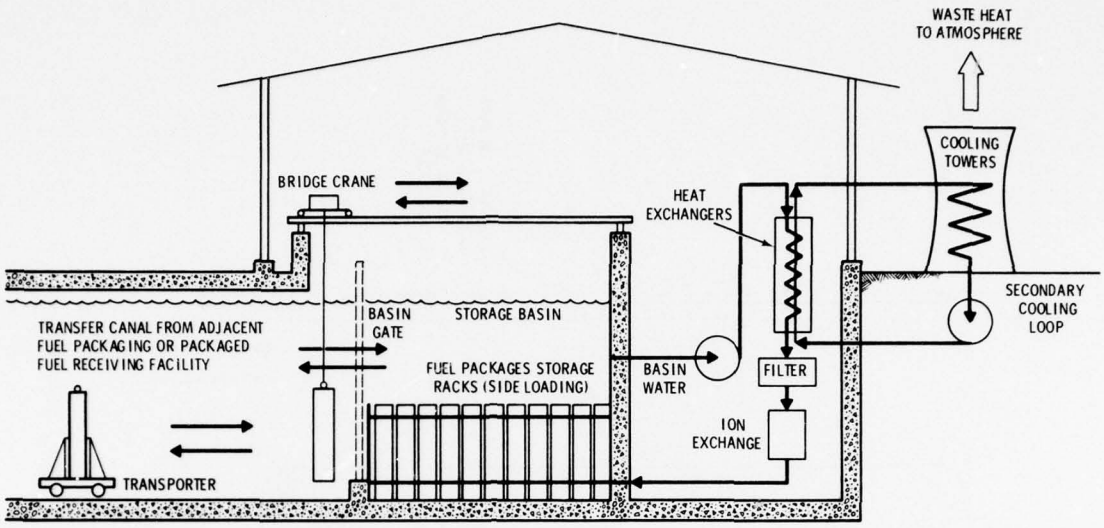


FIGURE 5.7.56. Schematic Operations Flow Diagram for Water Basin Storage of Packaged Spent Fuel

canal into each storage basin through a gate in the canal wall. The reference storage facility shares the adjacent facility's utilities, services, and support facilities, which include personnel areas, laboratories, health physics, warehousing, and maintenance shops.

Phase I construction includes only the first storage basin module, the first of the two basins nearest to the packaging facility. Phases II through X are yearly additions of water basin storage modules. Figures 5.7.58, 5.7.59 and 5.7.60 show the typical arrangement of a 2000-MTHM water storage basin and associated equipment. Each basin is built with reinforced concrete with 1.2-m (4-ft) thick walls. The basin is fully lined with stainless steel. Each basin module is covered by an insulated, dust tight building which houses the basin water cooling and treating equipment and a 10-ton bridge crane for handling the storage baskets. The equipment is at the end of the basin building opposite the transfer canal. The cooling tower for each basin is located outside the building and adjacent to the cooling equipment. The water basin storage arrangement does not provide transfer aisles; therefore, retrievability is limited to a first-in, last-out mode for each parallel row of storage. A minimum of 3.7 m (12 ft) of pool water provides shielding for the packaged spent fuel during storage.

The second basin module is directly across the transfer canal from the first basin. When the transfer canal is built it includes the gate opening and suitable construction tie-ins for adding the second basin while operating the canal and the first basin. The enclosure building and crane rails of the first basin are extended to cover the second basin. This construction process is repeated for the other basin pairs.

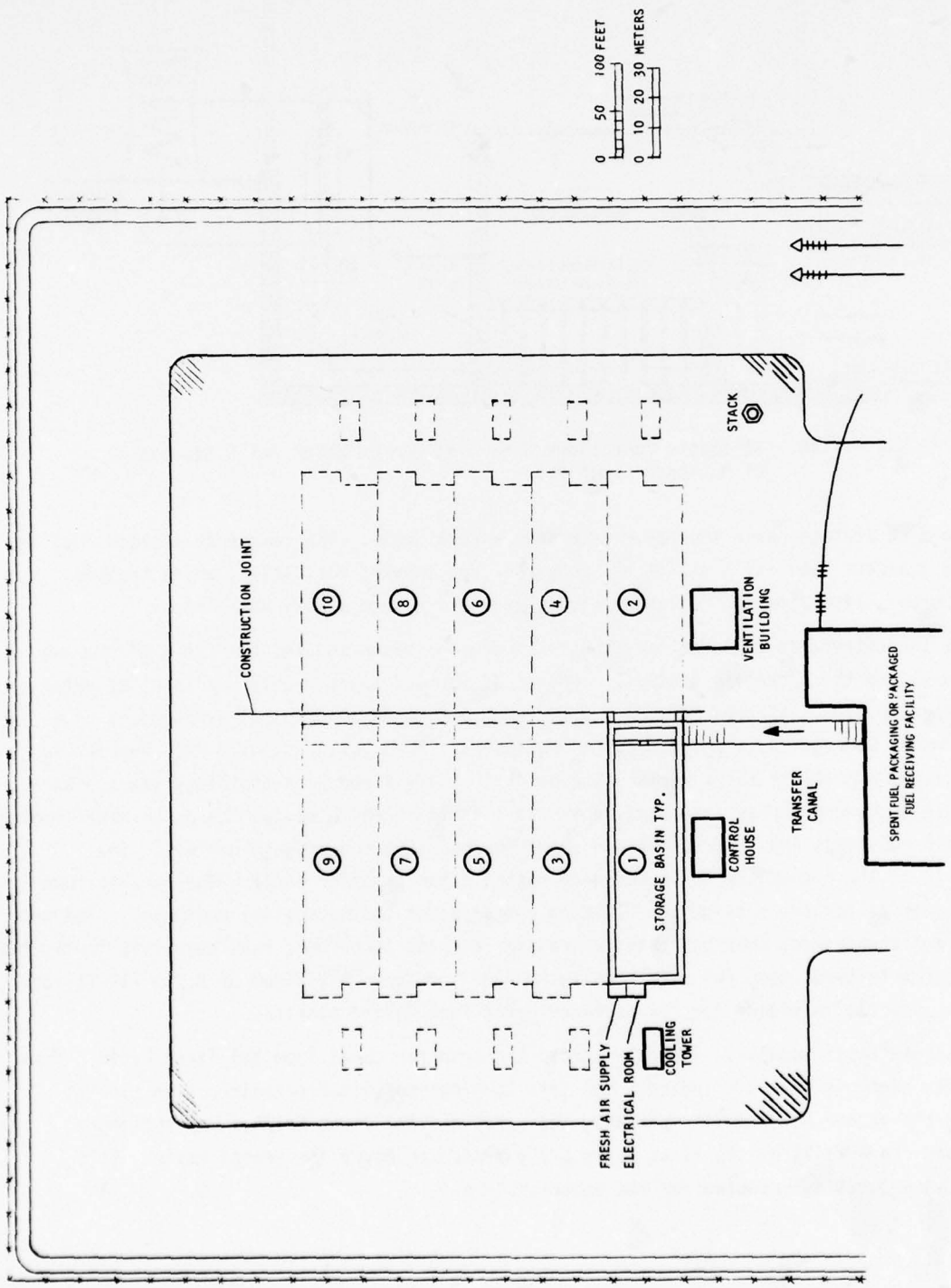


FIGURE 5.7.57. Facility for Water Basin Storage of Packaged Spent Fuel, Plot Plan

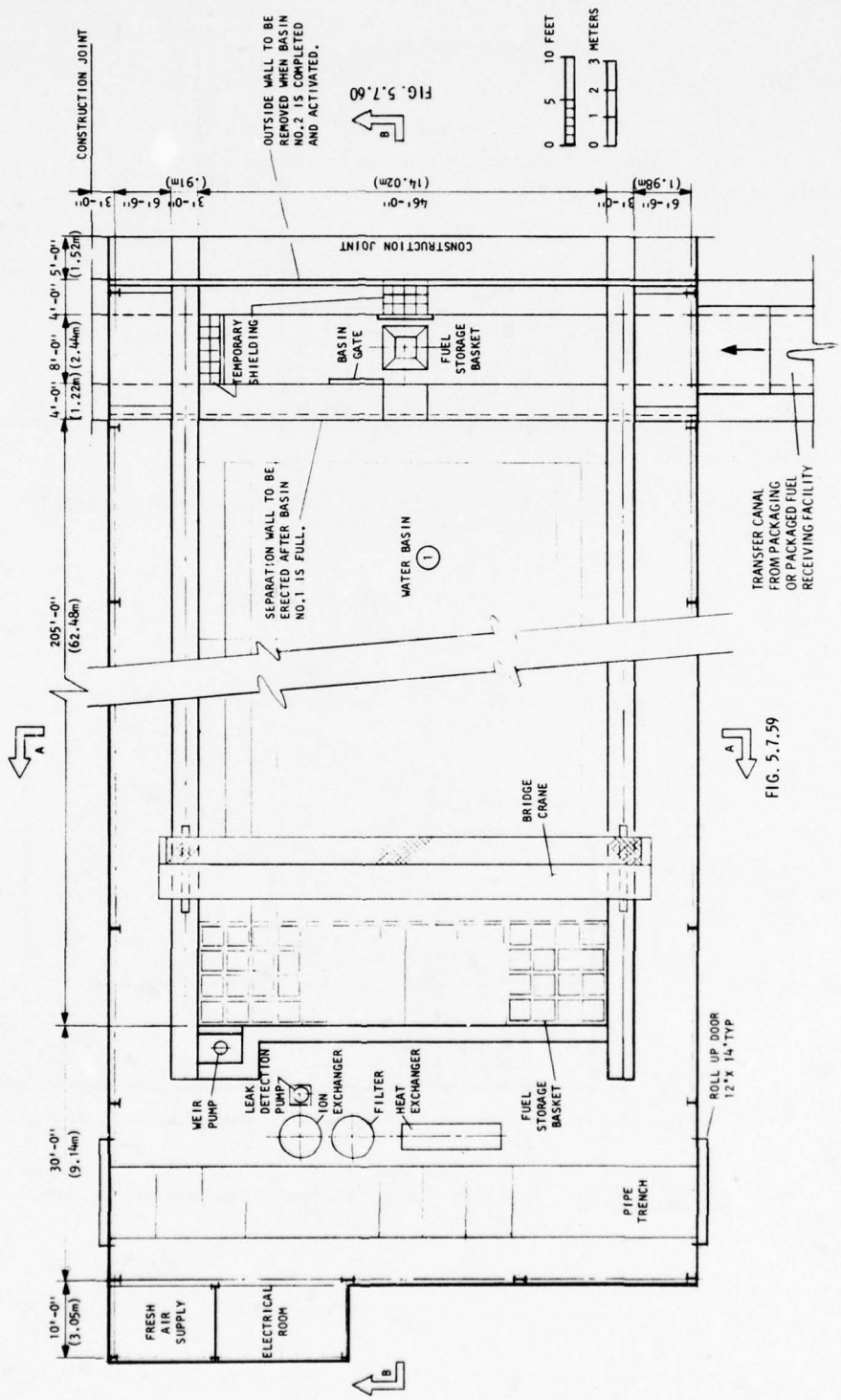


FIGURE 5.7.58. Facility for Water Basin Storage of Packaged Spent Fuel, General Arrangement

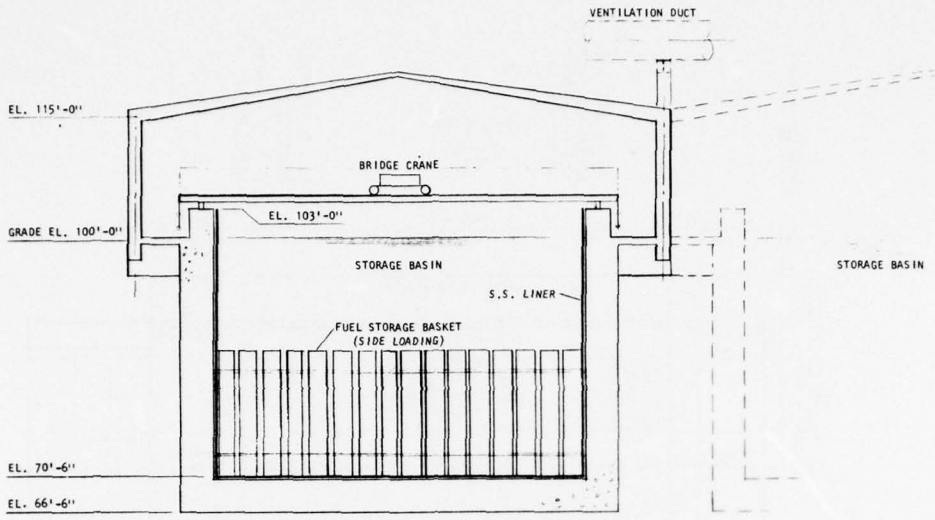


FIGURE 5.7.59. Facility for Water Basin Storage of Packaged Spent Fuel, Section A-A

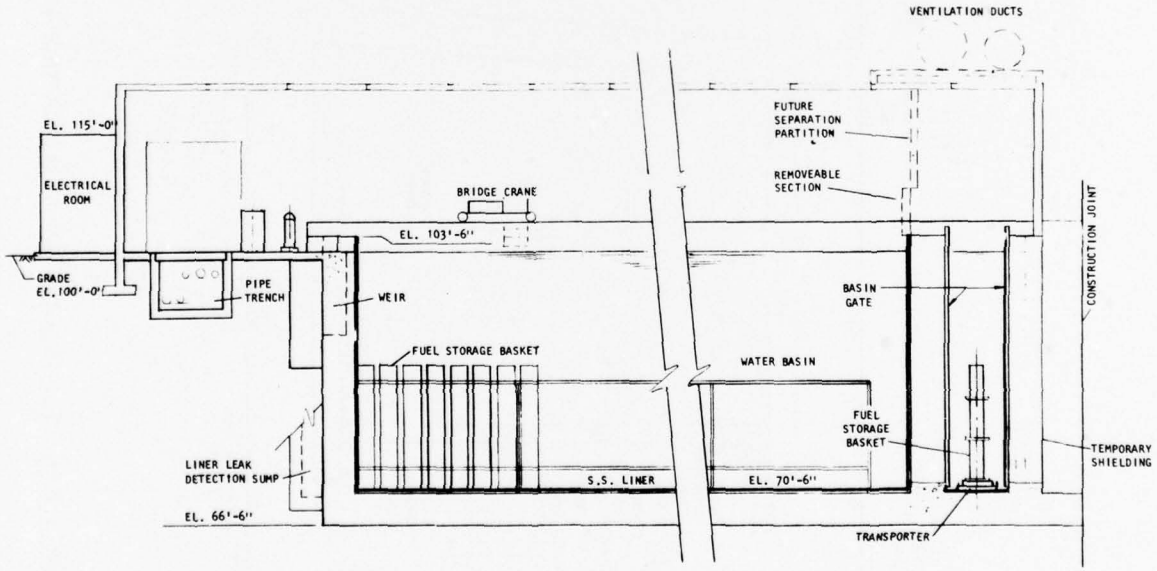


FIGURE 5.7.60. Facility for Water Basin Storage of Packaged Spent Fuel, Section B-B

Structures. The transfer canal, water basins, and the basket handling crane with its supports are Category I structures. The basin enclosure building, control house, ventilation filter/blower structure, and the cooling towers are standard commercial construction.

Systems and Equipment. Systems and equipment provided for the water basin storage of packaged spent fuel are described below.

Fuel Storage Baskets. Before transfer to the storage area, spent fuel packages are placed in storage baskets. Figures 5.7.61 and 5.7.62 show the PWR and BWR fuel storage baskets, which are fabricated from stainless steel.

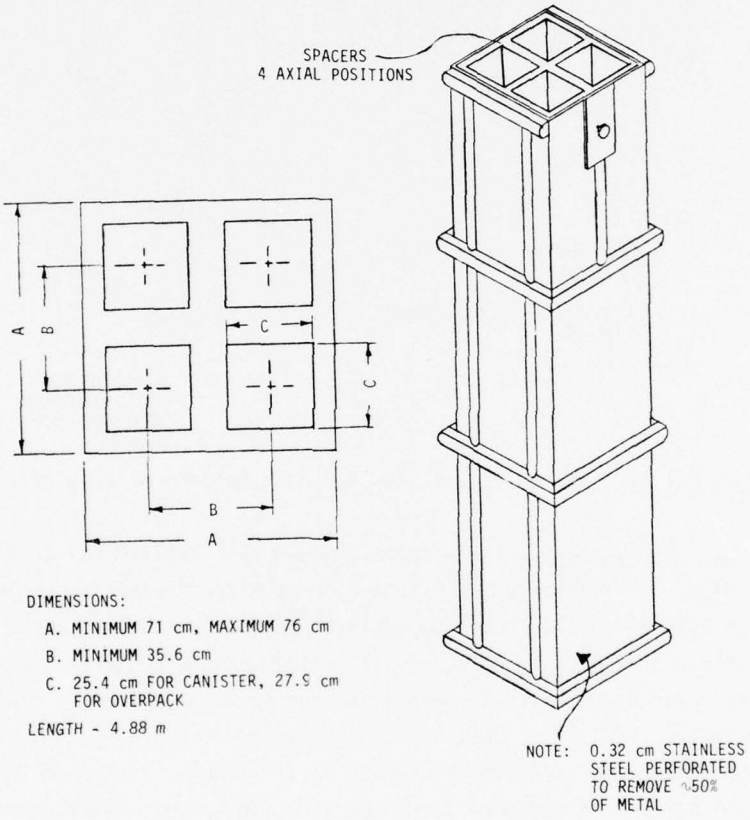


FIGURE 5.7.61. Storage Basket for Packaged Pressurized Water Reactor Fuel

Basin Storage Racks. Each basin contains a system of single-tiered, side-entering stainless steel storage racks for 1120 storage baskets. The racks are welded to the walls and floor of the basin. Each is 4.3 m (14 ft) high and runs the length of the basin. The baskets are moved into the racks one at a time on a first-in, last-out basis in each row. As each basket is moved into the last open position of a row, it is set into a tapered socket which holds the base of the basket in a fixed position. A bar locks in front of the basket at the top of the rack. This process is repeated for each basket so that each basket is securely emplaced. The rack framing is 10.0 cm (4 in.) wide, which ensures rigid construction and provides sufficient free space around the baskets to enhance the natural convective circulation of the basin cooling water.

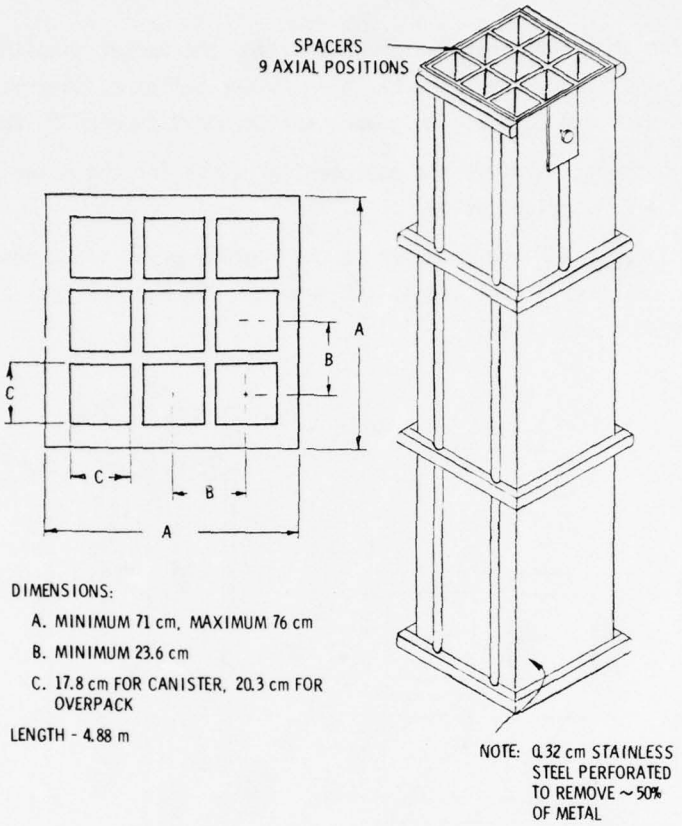


FIGURE 5.7.62. Storage Basket for Packaged Boiling Water Reactor Fuel

Basin Water Cooling Systems. The water from each basin system is circulated through a stainless steel plate-type cooler which exchanges heat with a secondary cooling water circuit. Each basin has an outside cooling tower to cool the secondary cooling water. A sidestream from the cooling water circulating pump discharge is routed through a filter and ion exchanger to remove any radioactive contamination. Immediately after being filled, a single water basin has a heat load of about 2.7 MW, which decays to 1.8 MW after 10 years of fuel storage. A breakdown of individual water basin and total storage facility heat loads as a function of time is presented in Table 5.7.49. A Category I emergency cooling water system guarantees the supply of basin makeup water if the cooling water circulation system fails because of damage from a tornado or earthquake.

Pool Leakage Control. A pool leakage collection system collects and returns any water which may leak through the liner of the pools. A system of interconnecting channels in the concrete behind the liner collects pool leakage and directs it to sumps where instruments detect it and set off an alarm. Sump pumps return this leakage to the basin through the pool water filter-deionizer system.

Ventilation Systems. Ventilation systems are designed for once-through flow of air. When the basin is being filled with packaged spent fuel, the storage building is ventilated with approximately 5 air changes per hour, which are discharged directly through the stack. Inlet

TABLE 5.7.49. Facility Heat Load

Elapsed Time After Initial Fuel Receipt, Years[a]	Quantity of Fuel at Facility, MTHM	Heat Load Initial 2000 MTHM, MW[a]	Total Heat Load, MW
1	2,000	2.7	2.7
2	4,000	2.5	5.2
3	6,000	2.3	7.6
4	8,000	2.2	9.8
5	10,000	2.1	11.9
6	12,000	2.1	14.0
7	14,000	2.0	15.9
8	16,000	1.9	17.9
9	18,000	1.9	19.7
10	20,000	1.8	21.6

a. Information based on no recycle fuel and exposure of 29,000 MWD/MTHM. Average age of fuel in each 2000-MTHM cell at the end of the fill period is 7 years from reactor discharge.

air passes through roughing filters to remove the bulk particulate matter in the ambient air. If radioactivity is detected in the exhaust air, flow is reduced and the air is automatically diverted through HEPA filters before release through the stack. This high capacity filter/blower station sequentially serves each basin module during its filling period.

When a storage pool is full, a low capacity blower installed at the basin building discharges air directly through the stack. This air flow keeps the air humidity over the pool area below the dew point. The air flow can be diverted to the high capacity filter/blower station if the air in any filled basin building becomes contaminated. Because two pools are enclosed in each building, a ventilation barrier is required to separate the air flows for each pool area.

Shielding and Remote Handling Equipment. The principal shielding material used in the reference facility is water, which provides a transparent medium for visual inspection and handling of the packaged fuel in the storage basins and transfer canals. Handling is by semiremote methods, i.e., cranes and extended tongs. Normal exposure to operating personnel is less than 1 mrem/hr. During infrequent operations, such as transfer of a damaged or leaking fuel package and subsequent clean-up procedures, dose rates higher than normal could be received, but the resultant doses would be controlled to well within the limits of Title 10, Part 20, of the Code of Federal Regulations.[8]

In case of high radiation levels in the basin water, piping used to transfer the water could be a potential radiation hazard; however, the additional confinement provided by the fuel packages results in very low radioactivity of basin water, and pipe shielding is not required. Equipment that could collect radioactivity, such as the ion exchange columns and filters, are flushed to remove radioactivity before maintenance operations are initiated. Either contact or semiremote maintenance techniques would be used, depending on the residual radioactivity level.

5.7.5.5 Operating and Maintenance Requirements for the Facility for Water Basin Storage of Packaged Spent Fuel

The reference facility is operated 24 hours a day, 7 days a week. Some particular operations, such as routine fuel package transfer, water cleanup system regeneration, and maintenance could be limited to the day shift, but critical operations, such as basin water cooling and monitoring, are continuous.

Staffing. The estimated staffing requirements for the reference facility are presented in Table 5.7.50.

TABLE 5.7.50. Staffing Requirements for the Facility for Water Basin Storage of Packaged Spent Fuel

Job Description	Personnel Required, man-yr/yr
Operators	27
Maintenance	18
Radiation monitors	5

Supplies and Utilities. Table 5.7.51 lists the supplies used in reference facility operation. Table 5.7.52 shows the utility requirements for reference facility operation.

TABLE 5.7.51. Water Basin Storage of Packaged Spent Fuel Supply Requirements

Material	Use	Annual Requirements
5% sodium hydroxide	Ion exchange bed regeneration	<570 m^3
5% nitric acid	Ion exchange bed	<380 m^3
Detergent		
SP-210[a]	Decontamination	<1 m^3
Powdered detergent	Cleaning	<0.1 m^3
Baskets	Hold fuel packages	
PWR		680
BWR		450

a. SP-210 is a decontamination agent of a proprietary composition containing detergent, wetting, and rinsing agents. It is used as a 10% by weight solution in water. The decontamination solution has a pH of 10.9 and a specific gravity of 1.05.

TABLE 5.7.52. Utility Requirements for Water Basin Storage of Packaged Spent Fuel (Maximum at End of Fill Period)

Utility	Use Rate	Annual Requirement
Electricity	3,000 kW	2.6×10^7 kWh
Water consumed	1,100 m^3/day	4.0×10^5 m^3
Steam	6.3×10^4 kg/day	2.3×10^7 kg
Coal	6.3×10^3 kg/day	2.3×10^6 kg

Hazardous Materials. The only hazardous material present during the operation of the water basin storage facility is the packaged spent fuel. Decontaminating agents are not normally used in the facility. Organic resins are used for basin water cleanup and are regenerated with acid and caustic. These materials are handled according to safe industrial practice.

5.7.5.6 Secondary Radioactive Wastes for the Facility for Water Basin Storage of Packaged Spent Fuel

Secondary radioactive wastes generated by the reference facility operation are shown in Table 5.7.53.

TABLE 5.7.53. Secondary Radioactive Wastes from the Facility for Water Basin Storage of Packaged Spent Fuel

Description	Volume, m^3/yr	Radioactivity Factors[a]		
		Activation Products	Fission Products	Actinides
Combustible and compactable waste	170	All 1×10^{-9}	All 1×10^{-11}	0
Wet wastes	5	All 1×10^{-7}	Cs 4×10^{-8} All others 1×10^{-9}	0
Failed equipment and noncombustible waste	10	All 1×10^{-10}	All 1×10^{-12}	0

a. Fraction of input activity in secondary wastes. For input use column 3 of Table 5.7.2 and 2000 MTHM/yr.

5.7.5.7 Emissions from the Facility for Water Basin Storage of Packaged Spent Fuel

The emissions from the reference facility operation are described in Table 5.7.54. The radionuclide releases are assumed to be negligible since the low release rates occurring during storage of unpackaged spent fuel (Section 5.7.1) would be further reduced by at least several orders of magnitude by containment of the fuel elements in high integrity packages.

TABLE 5.7.54. Emissions from the Facility for Water Basin Storage of Packaged Spent Fuel

Emissions	Description	Annual Quantity	Radioactivity Release to Atmosphere
Gaseous	Facility air and vaporized excess water	3.1×10^9 m^3	Negligible
	Minor accident integrated annual release		None identified
Cooling tower water	Evaporated (T = 38°C)	3.2×10^8 kg	
	Drift (T = 38°C)	1.5×10^6 kg	
	Blowdown (T = 27°C)	5.5×10^7 kg	
Other	Heat	$\leq 2.2 \times 10^5$ MW-hr (6.6×10^{11} BTU)	

5.7.5.8 Decommissioning Considerations for the Facility for Water Basin Storage of Packaged Spent Fuel

The principal items that may have minor residual radioactivity after facility shutdown would be the stainless steel basin and transfer canal liners, ion exchange columns, and filters. Potential lower level activity might be associated with the secondary heat exchanger, basin water piping, and ventilation system. Because decontamination takes place as needed during normal operation and because the spent fuel packaging greatly reduces the quantity of radioactivity released into the facility, decommissioning activities are less extensive than those required for water basin storage of unpackaged spent fuel. The design of the facility includes plans for decommissioning. The structures of the facility are designed for a 100 year life. Other equipment such as pumps, columns, heat exchanger, etc. are replaced periodically. A quality assurance program, begun during design, continues throughout the life of the facility. Materials are of known durability and allowances are made for corrosion, wear, and radiation damage. Surfaces that are susceptible to hard-to-remove radionuclide contamination are covered with a removable coating. Decommissioning equipment and systems are provided in the facility design. On cessation of reference facility operations, the facility is expected to be contaminated with less than 1 Ci of mixed fission products.

5.7.5.9 Postulated Accidents for the Facility for Water Basin Storage of Packaged Spent Fuel

The following precautions are taken to assure the safe storage of packaged spent fuel elements in the reference water basin facility:

- Category I structures provide physical protection and shielding of the fuel packages.
- Highly reliable and redundant systems are provided for water cooling, basin water make-up, atmospheric protection, and fuel containment.
- Operators are highly skilled and trained in normal and emergency operation of safety and containment systems.

The minor and severe accidents postulated for this facility are presented in Tables 5.7.55 and 5.7.56. These accidents are similar to those postulated for the facility for water basin storage of unpackaged spent fuel (Section 5.7.1.9); however, spent fuel packaging and placement in storage racks is expected to significantly reduce the potential effects of the accidents described for the unpackaged fuel storage facility. For this reason, cladding ruptures due to impact are not considered credible for packaged spent fuel in this facility.

The accidents listed as minor (Table 5.7.55) have occurred at facilities for storing unpackaged spent fuel in water basins. The severe accidents have not been experienced at a water basin storage facility. No accidents that could be classified as moderate accidents could be realistically are postulated for this facility.

5.7.5.10 Costs of the Facility for Water Basin Storage of Packaged Spent Fuel

The capital, operating, and levelized unit cost estimates have been made in mid-1976 dollars. A description of the bases, assumptions, and definitions used in these cost estimates is given in Section 3.8.

Capital Costs. The capital cost estimates for the facility to store packaged spent fuel in water basins are shown in Tables 5.7.57, 5.7.58, 5.7.59, and 5.7.60. Phase I is assumed to be built at the same time as the adjacent packaging facility or fuel receiving facility. Table 5.7.57 shows the capital cost estimated for this phase, which includes one 2000 MTHM storage water basin, the transfer water canal from the SFPF, the water cooling system for the water basin, a control house, and an emergency filter and blower station with capacity to handle ventilation air from a storage basin module while it is being filled. The rough grading to prepare the overall site for the ultimate 20,000 MTHM storage capacity is also included in Phase I.

Table 5.7.58 shows the capital cost estimate for Phase II. Phase II adds one 2000-MTHM storage water basin which will be ready to operate at the start of the second year. Phase II is a mirror image expansion of Phase I. The basin building is expanded to cover the second basin; crane rails for the fuel basket handling crane are also extended.

Table 5.7.59 shows the capital cost estimate for Phase III, which adds another 2000-MTHM storage water basin. Phase III includes an extension of the transfer canal to a basin module identical to the Phase I configuration. For this reason, Phase III is more costly than Phase II.

TABLE 5.7.55. Postulated Minor Accidents for the Facility for Water Basin Storage of Packaged Spent Fuel

Accident No. and Description	Sequence of Events	Safety System	Release
5.7.21 – Loss of normal electrical power; expected frequency 0.175/yr.	1. Power to substation supplying the packaged spent fuel storage facility interrupted.	1. Automatic brakes activated by power loss.	None
	2. Equipment motion stops.	2. Emergency diesel generator.	
	3. Emergency power supplied to facility.		
	4. Operations resumed.		
5.7.22 – Loss of normal cooling water supply; expected frequency 0.175/yr.	1. Cooling water supply stops due to power outage.	1. Emergency diesel generator.	None
	2. Emergency power supplied to cooling water pumps.		
5.7.23 – Reduction of normal cooling water supply; expected frequency 0.25/yr.	1. Pump or heat exchanger failure.	1. Pools have temperature instrumentation.	None
	2. Temperature begins to slowly rise in pool.	2. Back-up pumps are installed.	
	3. Emergency cooling provided.		
	4. Pool temperature reduced to normal.		
5.7.24 – Ventilation system failure; expected frequency 0.25/yr.	1. Failure of exhaust or supply fan motor.	1. Redundant ventilation exhaust and supply.	None
	2. Back-up system automatically starts up.		
5.7.25 – Leak in water treatment system; expected frequency 0.25/yr.	1. Gasket fails; pool water leaks to floor.	1. Leak collection system and alarms.	None
	2. Leakage enters sump and triggers a high level alarm.		
	3. Leakage returned to pool and leak repaired.		
	4. Spill area decontaminated.		
• 5.7.26 – Dropped fuel rack in transfer tunnel	1. Rack grapple, grapple lifting cable, or cable winch fails when filled fuel rack is moved to water basin.	1. Canister and rack designed to withstand such a fall without loss of integrity.	None
	2. Filled rack falls to bottom of transfer tunnel.		

TABLE 5.7.56. Postulated Severe Accidents for the Facility for Water Basin Storage of Packaged Spent Fuel

Accident No. and Description	Sequence of Events	Safety System	Release
5.7.27 – Design basis tornado; expected frequency 1×10^{-5}/yr.	1. Identical to Accident 5.7.12.	1. See Accident 5.7.12 2. Stainless steel canister protects fuel.	Releases from this accident are expected to be much less than accident 5.7.12 (3.3×10^{-3} Ci of mixed fission products in 16.5 MT of basin water) because radioactivity levels in the basin water are lower due to the canisters protecting the fuel.
5.7.28 – Criticality; expected frequency 1×10^{-5}/yr.	1. Identical to Accident 5.7.13.	1. Same as Accident 5.7.13. 2. Reactivity of the fuel is reduced because the stainless steel canister would keep all water away from the fuel bundle.	Conservatively estimated to be the same as Accident 5.7.13.
5.7.29 – Loss of cooling water supply.	1. Cooling towers become inoperative due to damage or mechanical failure. 2. Emergency cooling water supplied to basin heat exchangers before any fuel assemblies are damaged.	1. Highly reliable (design and redundancies) cooling pond available for emergency cooling. 2. Heat exchanger equipment is highly reliable (design redundancies).	None

TABLE 5.7.57. Capital Cost Estimate for Water Basin Storage of Packaged Spent Fuel, Phase I - Initial Construction Including One 2000-MTHM Storage Module

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		30	2,000	300	2,300
Buildings and structures		600	4,100	7,200	11,300
Bulk materials		90	1,200	1,200	2,400
Site improvements		40	100	500	600
Subtotal of direct site construction costs		760	7,400	9,200	16,600
Indirect site construction costs	200	150	3,400	4,400	7,800
Total field cost	200	910	10,800	13,600	24,400
Architect-engineer services					4,900
Subtotal					29,300
Owner's cost					8,700
Total facility cost					38,000
Estimated accuracy range					±25%

Note: The costs for PWR and BWR storage baskets fabricated from stainless steel are not included in the facility cost estimates. The estimated unit costs for these items are $9,500 (PWR) and $10,000 (BWR) based on procurement in lots of 100 or more.

TABLE 5.7.58. Water Basin Storage of Packaged Spent Fuel Facility Capital Cost Estimate, Phase II - Addition of One 2000-MTHM Storage Module

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		20	1,300	200	1,500
Buildings and structures		380	2,300	4,600	6,900
Bulk materials		60	450	700	1,150
Site improvements		20	50	300	350
Subtotal of direct site construction costs		480	4,100	5,800	9,900
Indirect site construction costs	130	90	2,100	2,800	4,900
Total field cost	130	570	6,200	8,600	14,800
Architect-engineer services					2,900
Subtotal					17,700
Owner's cost					5,300
Total facility cost					23,000
Estimated accuracy range					±25%

Note: Phase II is ready for operation at start of the 2nd year. It is a mirror image of the previous storage basin with an extension of a common building and using the same handling crane. No additional transfer crane is required.

TABLE 5.7.59. Water Basin Storage of Packaged Spent Fuel Facility Capital Cost Estimate, Phase III - Parallel Addition of One 2000-MTHM Storage Module

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		20	1,400	200	1,600
Buildings and structures		450	2,900	5,500	8,400
Bulk materials		60	480	700	1,180
Site improvements		10	20	100	120
Subtotal of direct site construction costs		540	4,800	6,500	11,300
Indirect site construction costs	140	110	2,400	3,200	5,600
Total field cost	140	650	7,200	9,700	16,900
Architect-engineer services					3,100
Subtotal					20,000
Owner's cost					6,000
Total facility cost					26,000
Estimated accuracy range					±25%

Note: Phase III is ready for operation at the start of the 3rd year. It is a duplicate of the storage module built in Phase I plus an extension of the transfer canal. Phases V, VII, and IX are duplicates of Phase III.

TABLE 5.7.60. Water Basin Storage of Packaged Spent Fuel Facility Capital Cost Estimate, Phase IV - In-Line Addition of One 2000-MTHM Storage Module.

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		20	1,300	200	1,500
Buildings and structures		370	2,200	4,400	6,600
Bulk materials		60	480	700	1,180
Site improvements		10	20	100	120
Subtotal of direct site construction costs		460	4,000	5,400	9,400
Indirect site construction costs	120	90	2,000	2,600	4,600
Total field cost	120	550	6,000	8,000	14,000
Architect-engineer services					2,900
Subtotal					16,900
Owner's cost					5,100
Total facility cost					22,000
Estimated accuracy range					±25%

Note: Phase IV is ready for operation at the start of the 4th year. It is a duplicate of the storage module built in Phase III except that the storage building has a common wall with Phase II and the amount of site work is less. Phases VI, VIII, and X are duplicates of Phase IV.

Phase IV is a duplicate of the storage module built in Phase II, except that the storage building has a common wall with Phase II and the amount of site work is less for Phase IV than for Phase II. The Phase IV cost estimate is shown in Table 5.7.60. Phases V, VII and IX are essentially identical to Phase III; Phases VI, VIII and X are essentially identical to Phase IV.

Each estimate covers all capital costs resulting specifically from the addition of the storage facility component to the adjacent packaging or receiving facility. All utilities are supplied from the adjacent facility. The storage facility cost includes allowances for incremental utility capacity additions to the adjacent facility and for increments for personnel facilities, such as change rooms, lunch rooms, lavatories, and so on. No allocation of general adjacent facility costs is made to the storage facility for support services, such as laboratories, warehouses, administration office, and maintenance shops.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation. These costs exclude working capital and the cost of handling baskets; the latter cost is included in the operating cost estimate. The costs of carbon steel canisters and overpacks are included in the packaging facility costs. Incremental costs for stainless steel canisters and overpacks are included in the operating costs for the reference facility.

Operating Cost. Costs for one year's operation of the facility when receiving and storing fuel at the rate of 2000 MTHM per year are shown in Table 5.7.61. Direct labor costs are based on manpower estimates given in Table 5.7.50. Process materials costs include the cost of using stainless steel canisters and overpacks instead of the carbon steel units defined in the packaging facility estimates. Also included in this category are 673 PWR stainless steel storage baskets costing $9,500 each and 446 BWR baskets at $10,000 each. Utility costs are derived from requirements shown in Table 5.7.51. Annual maintenance materials costs are estimated at 3% of initial major equipment costs. Overhead and miscellaneous costs are estimated using the standard method described in Section 3.8.

TABLE 5.7.61. Operating Cost Estimate for Water Basin Storage of Packaged Spent Fuel

Cost Element	Annual Costs, $1,000's	
Direct labor	750	
Process materials	33,350	
Utilities	100	
Maintenance materials	100	
Overhead	900	
Miscellaneous	100	
TOTAL	35,300	±25%

Levelized Unit Cost. Table 5.7.62 shows the total levelized unit cost as well as the levelized capital and operating unit cost. The cost calculations assume Federal ownership of the facility. The facility starts receiving spent fuel at a rate of 700 MTHM the first year, 1300 MTHM the second year, followed by nine years of receipt and storage of 2000 MTHM (1 module) per year for a total accumulation of 20,000 MTHM. Following the last year of receiving spent fuel, the facility is unloaded at the rate of 2000 MTHM per year. It is then decommissioned. Decommissioning costs are estimated at 10% of the total initial capital costs. If an extended storage period were assumed, the unit storage cost would change only slightly since most of the costs are facility and hardware costs.

The reference facility design uses rectangular canisters and overpacks. If round canisters were used, the incremental costs per canister for stainless steel canisters would drop about 22% or $67 million for a 20,000 MTHM facility. This would decrease the unit cost by about $3.40/kg of heavy metal. However, if round canisters were used, the facility configurations would have to change substantially. Storage volume requirements and capital costs would probably increase. Also, since fewer round canisters could be transported in a spent fuel cask, the unit-packaged spent fuel transportation cost would increase.

TABLE 5.7.62. Levelized Unit Cost Estimate for Water Basin Storage of Packaged Spent Fuel

Cost Element	Unit Cost, $/kg HM
Levelized capital charge	14.30
Levelized operating charge	18.50
Levelized total unit cost	32.80 ±20%

5.7.5.11 Construction Requirements for the Facility for Water Basin Storage of Packaged Spent Fuel

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating this impact.

Project Schedules and Construction Manpower. The storage facility initial construction phase occurs at the same time as the construction of the adjacent facility. Section 5.7.3.11 describes the schedule for engineering, procurement, and construction of an adjacent spent fuel packaging facility. The schedule for the storage facility is the same as for an adjacent packaged spent fuel receiving facility. The field labor force estimated for the initial (Phase I) construction of the reference storage facility is shown below. These construction man-hours are integrated with labor schedules for the adjacent spent fuel packaging or packaged fuel receiving facility (Sections 5.7.3.11 and 5.7.4.11 respectively).

	Man-hours, 1000s
Manual field labor	910
Nonmanual field labor	200
Total field labor	1110

The field labor force estimated for the Phase II (2nd year) addition of one in-line storage module is shown below:

	Man-hours, 1000s
Manual field labor	570
Nonmanual field labor	130
Total field labor	700

The field labor force estimated for the Phase III (3rd year) addition of one parallel storage basin module is:

	Man-hours, 1000s
Manual field labor	650
Nonmanual field labor	140
Total field labor	790

The above estimate is the same for construction Phases V, VII and IX.

The field labor force estimated for the Phase IV (4th year) addition of one in-line storage basin module is:

	Man-hours, 1000s
Manual field labor	550
Nonmanual field labor	120
Total field labor	670

The above estimate is the same for construction Phases VI, VIII and X.

Distribution of Onsite and Offsite Costs. Onsite costs are those costs for all construction, materials, and services provided at the site of the storage facility, while offsite costs are those costs for all services, equipment fabrication or assembly, and materials purchased elsewhere. The distribution of total costs in these categories is as shown below:

	Costs, $1000s			
	Phase I	Phase II	Phases III, V, VI & IX	Phases IV, VI, VIII & X
Onsite	15,000	10,000	11,000	9,000
Offsite	23,000	13,000	15,000	13,000
Total	38,000	23,000	26,000	22,000

Site Requirements. The major siting restriction is that the reference facility not be located in a flood plain. Requirements for facility location include:

- access to large supply of water,
- access to rail and highway,
- access to moderate supply of electrical power, and
- minimum conflict with other beneficial land uses.

Land commitments for the storage facility are included with those for the adjacent facility; approximately 6.4 ha (16 acres) of land area are required for the storage facility alone.

Water. Approximately 15,000 m^3 (4.0 x 10^6 gal) of water are required during the initial (Phase I) construction period. During each of the construction Phases II through X, 11,000 m^3 (3.0 x 10^6 gal) of water are used.

Construction Materials. Materials committed to facility construction are:

	Phase I		Phase II		Phase III[a]		Phase IV[a]	
Concrete	5,300 m^3	(7,000 yd^3)	3,400 m^3	(4,500 yd^3)	4,200 m^3	(5,500 yd^3)	3,400 m^3	(4,500 yd^3)
Steel	1,700 MT	(1,900 tons)	1,100 MT	(1,200 tons)	1,200 MT	(1,300 tons)	1,000 MT	(1,100 tons)
Copper	18 MT	(20 tons)	14 MT	(15 tons)	14 MT	(15 tons)	14 MT	(15 tons)
Zinc	4.5 MT	(5 tons)	4 MT	(4 tons)	4 MT	(4 tons)	3 MT	(3 tons)
Lumber	470 m^3	(200 MFBM)	260 m^3	(110 MFBM)	310 m^3	(130 MFBM)	260 m^3	(110 MFBM)
Propane	130 m^3	(35,000 gal)	76 m^3	(20,000 gal)	95 m^3	(25,000 gal)	75 m^3	(20,000 gal)
Diesel fuel	1,325 m^3	(350,000 gal)	760 m^3	(200,000 gal)	950 m^3	(250,000 gal)	760 m^3	(200,000 gal)
Gasoline	850 m^3	(225,000 gal)	570 m^3	(150,000 gal)	605 m^3	(160,000 gal)	530 m^3	(140,000 gal)
Electricity								
Peak demand, kW	1,000		600		700		600	
Total consumption kWh	650,000		400,000		450,000		380,000	

a. Phases V, VII and IX quantities are the same as for Phase III; Phases VI, VIII, and X, are the same as Phase IV.

Transportation Requirements. No separate transportation requirements for the storage facility have been identified other than those for the adjacent packaging or packaged fuel receiving facility.

5.7.5.12 Effects of Fuel Cycle Options

Once-Through Cycle. A long storage period prior to final repository availability may favor storing spent fuel in the packaged form.

Recycle of Uranium or Plutonium. A long storage period prior to a reprocessing decision or reprocessing plant availability may favor storing the spent fuel in the packaged form.

5.7.6 Air-Cooled Vault Storage of Packaged Spent Fuel

A second alternative for extended storage of packaged spent fuel would involve packaging in individual carbon steel containers (as discussed in Section 5.7.3) and storing in heavily shielded, air-cooled concrete vaults. Spent fuel decay heat is transfered by natural convection to the air which flows past the packaged fuel. Vault air flow is induced by a chimney effect. The spent fuel packages are physically protected by the massive vault structure. This concept is an adaptation of a storage concept for solidified high-level waste.[17] Although at this time no facilities are using these design principles, the basic technology is fairly well established.

5.7.6.1 Alternatives for Air-Cooled Vault Storage of Packaged Spent Fuel

The alternatives for the air-cooled vault concept include primary cooling by forced air circulation rather than natural air circulation and above ground vaults rather than below ground vaults. Natural air circulation was selected for the reference facility so that the storage system is completely passive; i.e., it relies upon no mechanical operating equipment for heat removal. The underground (partially submerged) vault alternative was chosen because it economically provides increased structural strength and physical protection for spent fuel. Increasing the wall thickness of the vaults would have the same result but at a greater expense. An additional feature of the reference facility conceptual design is the use of carbon steel sleeves which surround the fuel canisters. These increase the natural air flow velocity around the canisters and provide additional heat transfer area for the air coolant. This lowers canister temperatures and enables closer packing of the spent fuel assemblies in the vault.

Employing natural convection air circulation does not permit filtration of the exit air because of the pressure drop across the filters. Double containment of the spent fuel is provided by single encapsulation of unfailed fuel assemblies (cladding is one barrier and the canister is the second) and by double encapsulation (overpacking) of any failed assemblies. A more conservative approach would be to doubly encapsulate all of the assemblies.

5.7.6.2 Design Basis for the Facility for Air-Cooled Vault Storage of Packaged Spent Fuel

The following assumptions were made in the design of the reference facility:

- The storage facility is located adjacent to a modified unpackaged spent fuel storage facility and its associated spent fuel packaging facility, or an independent packaged spent fuel receiving facility where it obtains all of its utilities and services.
- Packaged spent fuel is received at a rate of 2000 MTHM/year.
- The average exposure of the spent fuel is approximately 29,000 MWD/MTHM and it is aged at least 6.5 years from reactor discharge.

- The facility stores the packaged spent fuel assemblies in cells with a storage capacity of 2000 MTHM each (maximum heat load 2.7 MW per cell).* Additional cells are built as required to provide up to 20,000 MTHM (or 10 cells).
- The facility provides passive air cooling for individually packaged fuel assemblies.
- Only fuel from pressurized water reactors (PWR) and boiling water reactors (BWR) is stored in the reference facility.
- The facility accommodates four sizes of containers: PWR and BWR canisters and PWR and BWR overpacks.
- Canisters and overpacks are made of carbon steel.
- The spent fuel packages are placed inside carbon steel sleeves to improve cooling.
- Credit for neutron absorption in the canisters is taken when determining the critically safe spacing of the canisters.
- A monitoring system checks the air exiting the vault for helium and fission products.
- Vault design provides for ready retrieval of fuel packages at any time.

5.7.6.3 Operation of the Facility for Air-Cooled Vault Storage of Packaged Spent Fuel

A schematic flowsheet which describes the air-cooled vault storage facility (ACVSF) operations is given in Figure 5.7.63.

Packaged spent fuel assemblies are moved from the adjacent packaging or receiving facility to the ACVSF through an underground tunnel on a motor-drawn, track-mounted cart. The cart has two racks: one carries four PWR assemblies and the second carries nine BWR assemblies in the same configurations used in the storage vault. A crane loads the spent fuel containers onto the cart one at a time in the adjacent facility. If spent fuel packaging failure should occur, the cart is remotely retrievable.

The cart moves to the storage vault area of the ACVSF and is positioned in the tunnel for crane transfer of the spent fuel to a shielded loading cask. After being moved into position over the tunnel plug, the canister charging crane removes the plug onto the cask apron on the crane. The crane then positions the shielded cask directly over the tunnel cavity. The multiple grapple suspended from the top mounted cask hoist picks the containers from the tunnel cart rack and lifts them into the shielded cask. The canisters are secured within the cask to prevent dropping or swaying of spent fuel packages while the crane is in motion. The crane is then moved back so that it can replace the plug in the tunnel roof. The crane next moves to the designated storage position where it removes the storage plug, deposits the containers into the storage sleeves, and replaces the storage plug.

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* It is assumed that 2000 MTHM can be stored in a single air-cooled cell (same heat load as single cell for storage of solid HLW per reference 17, i.e., 2.7 MW vs 2.5 MW).

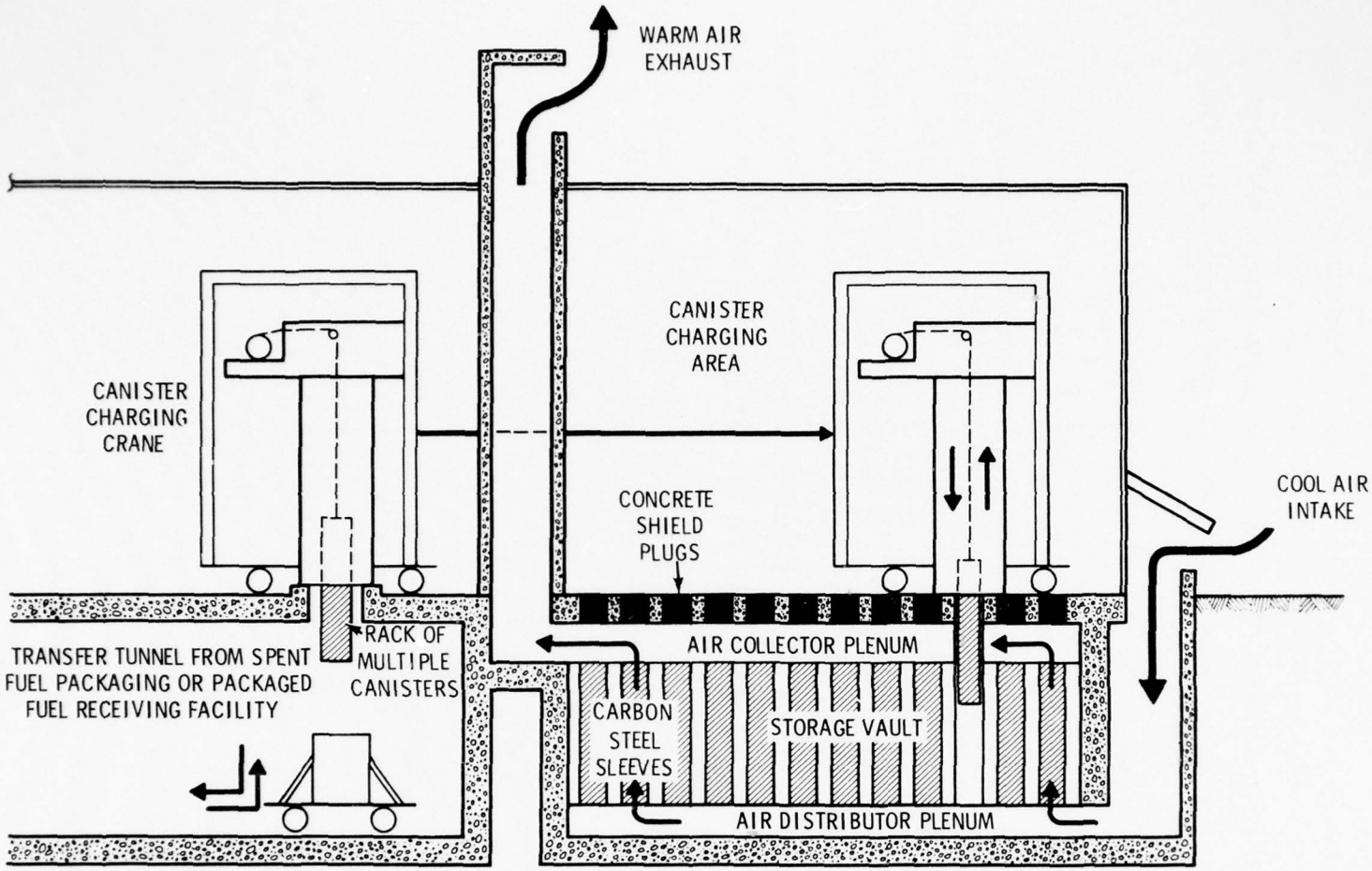


FIGURE 5.7.63. Operations Flowsheet for ACVSF

Ambient air enters inlet plenums through sheltered louvers on each side of the vault. Air flows lengthwise through the annulus between the vault sleeves and the outside surface of each container. As the air flows to the upper plenum, it picks up the container-generated heat. This heated air flows to the central vertical stack section and out the louvers at the top of the stack. This cross-flow pattern is uniform over the length of the storage vault.

Air sampling probes are located in each stack section to detect the presence of helium or radioactivity in the exit air. If container failure is indicated, top dampers in the stack are closed and the contaminated air is diverted through a sand filter by forced draft exhaust blowers. The failed spent fuel package is located and removed to a facility for repackaging or overpacking. Package failure is expected to be rare or nonexistent.

The heat load in each 2000 MTHM storage cell at the time it is filled is ∿2.7 MW (see Table 5.7.49, Section 5.7.5.3). Transfer of this heat through the canister walls to the air between the canister and sleeve promotes circulation of cooling air through the cell. An analysis of this specific case of heat-induced circulation through a spent fuel storage cell has not been made; however, such an analysis was made[17] for natural draft cooling of solidified high-level waste in a similar storage cell with a heat load of ∿2.5 MW. The major difference between the HLW storage concept and the concept for storage of packaged spent fuel is the significant difference in heat load at each position, 5 kW for a HLW container compared to about 0.66 kW for a PWR package and about 0.27 kW for a BWR package.

Maximum temperatures for canistered fuel element assemblies both with and without overpacks were calculated assuming that the helium in the containers leaked from the package and was replaced by air (the thermal conductivity of helium is a factor of 5 higher than that for air). Results showed that with an average air temperature of ∿70°C (160°F) in the annulus between package and sleeve, the maximum pin temperature for a PWR assembly in a canister was ∿240°C and in a canister and overpack ∿260°C. For a BWR assembly, canistered and overpacked, the maximum pin temperature was ∿175°C.

5.7.6.4 Description of the Facility for Air-Cooled Vault Storage of Packaged Spent Fuel

The reference facility consists of ten partially buried storage vaults, two sand filters, an underground transfer tunnel, and various equipment for transporting fuel packages.

As indicated in Figure 5.7.64, the air-cooled vault storage facility is located adjacent to either a spent fuel packaging or a packaged spent fuel receiving facility. Figures 5.7.65, 5.7.66, and 5.7.67 show the arrangement of each storage vault module.

Structures. The transfer air tunnel and the air-cooled storage vault are massive Category I reinforced concrete structures which provide biological shielding from spent fuel radiation and protection against extreme natural phenomena, such as earthquakes and tornadoes. The storage vaults have 1.2 m (4 ft) minimum thickness walls, roof, and floor. The top surface of the storage vault is about 0.3 m (1 ft) above grade, with the remainder of the vault buried in the earth. The roof and the storage space of the vault are supported by perimeter walls and interior columns or walls. Spent fuel packages are stored vertically and are bottom supported.

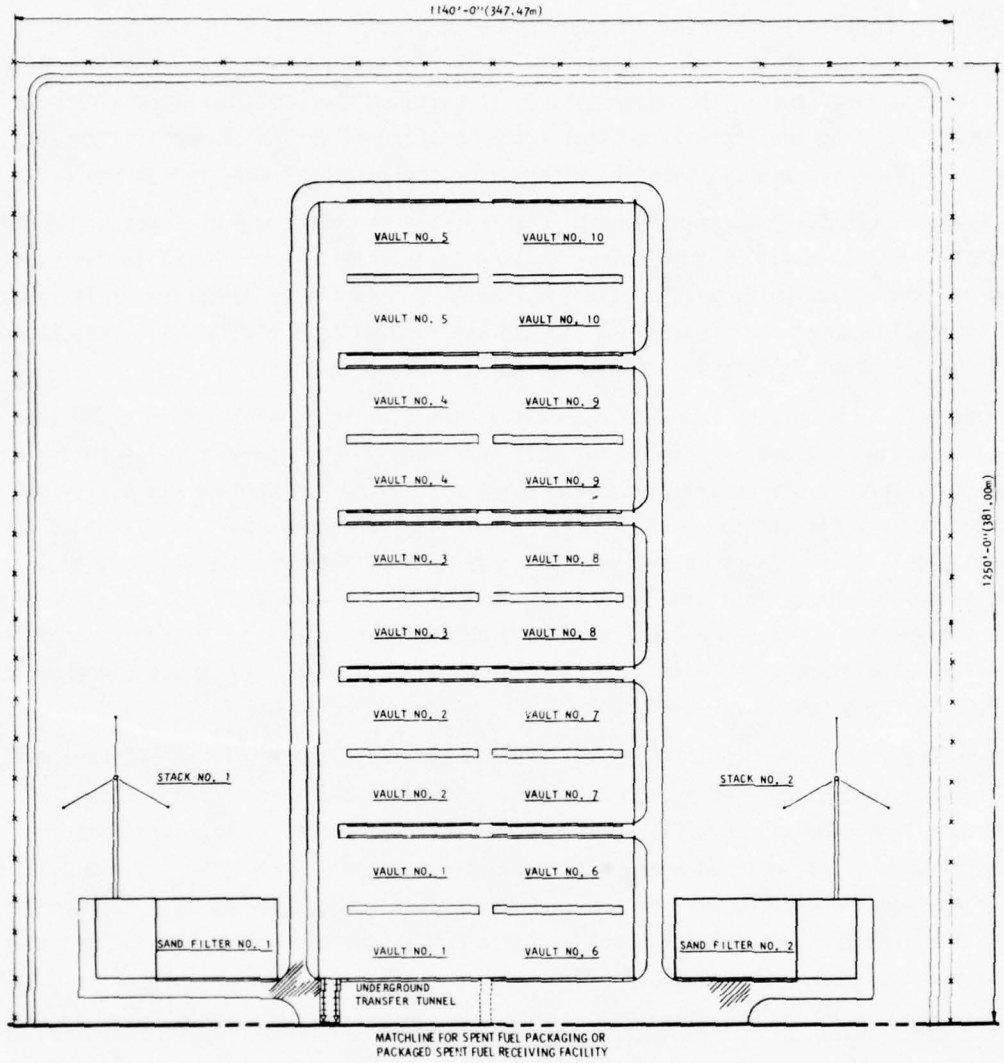


FIGURE 5.7.64. ACVSF Plot Plan

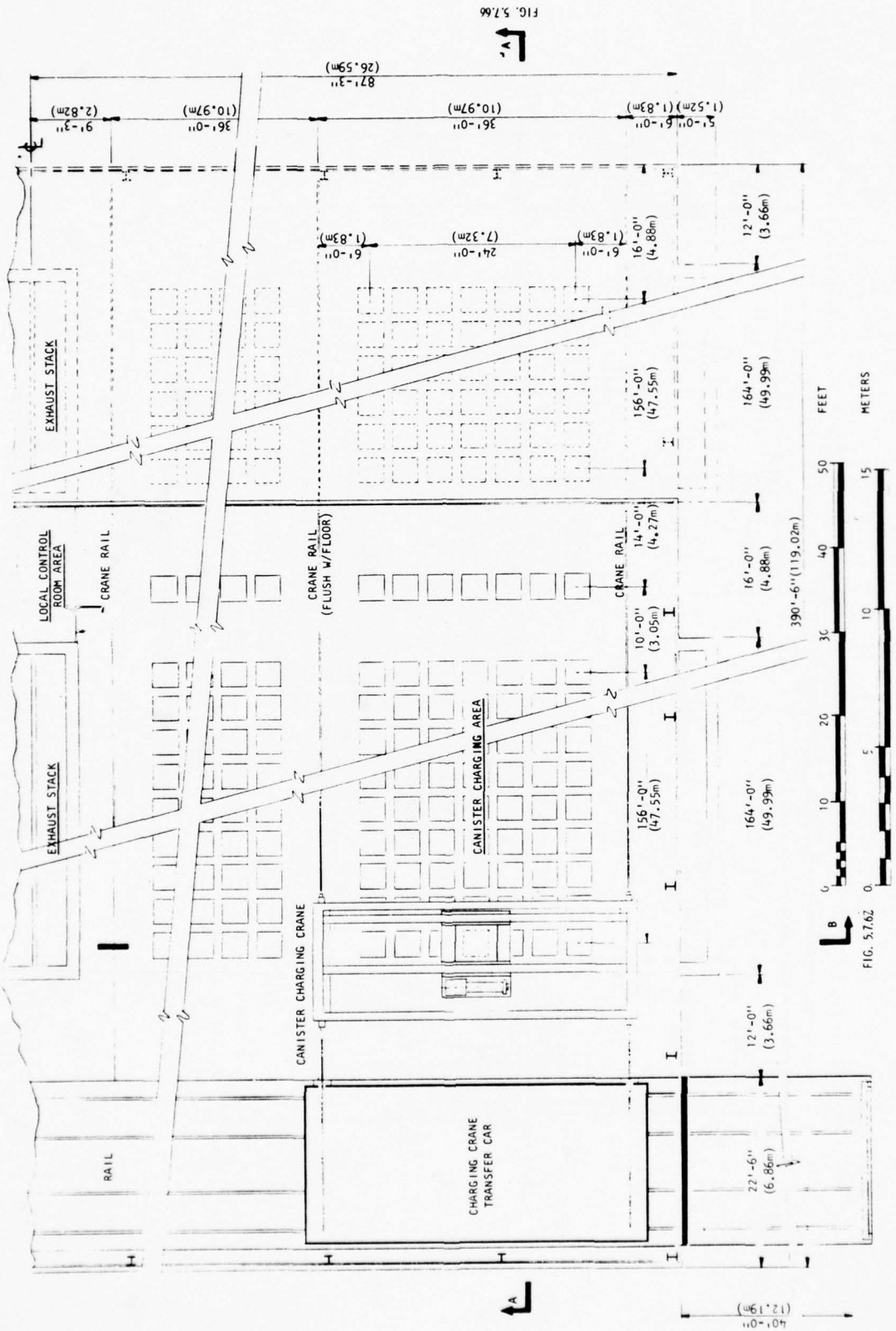


FIGURE 5.7.65. ACVSF General Arrangement

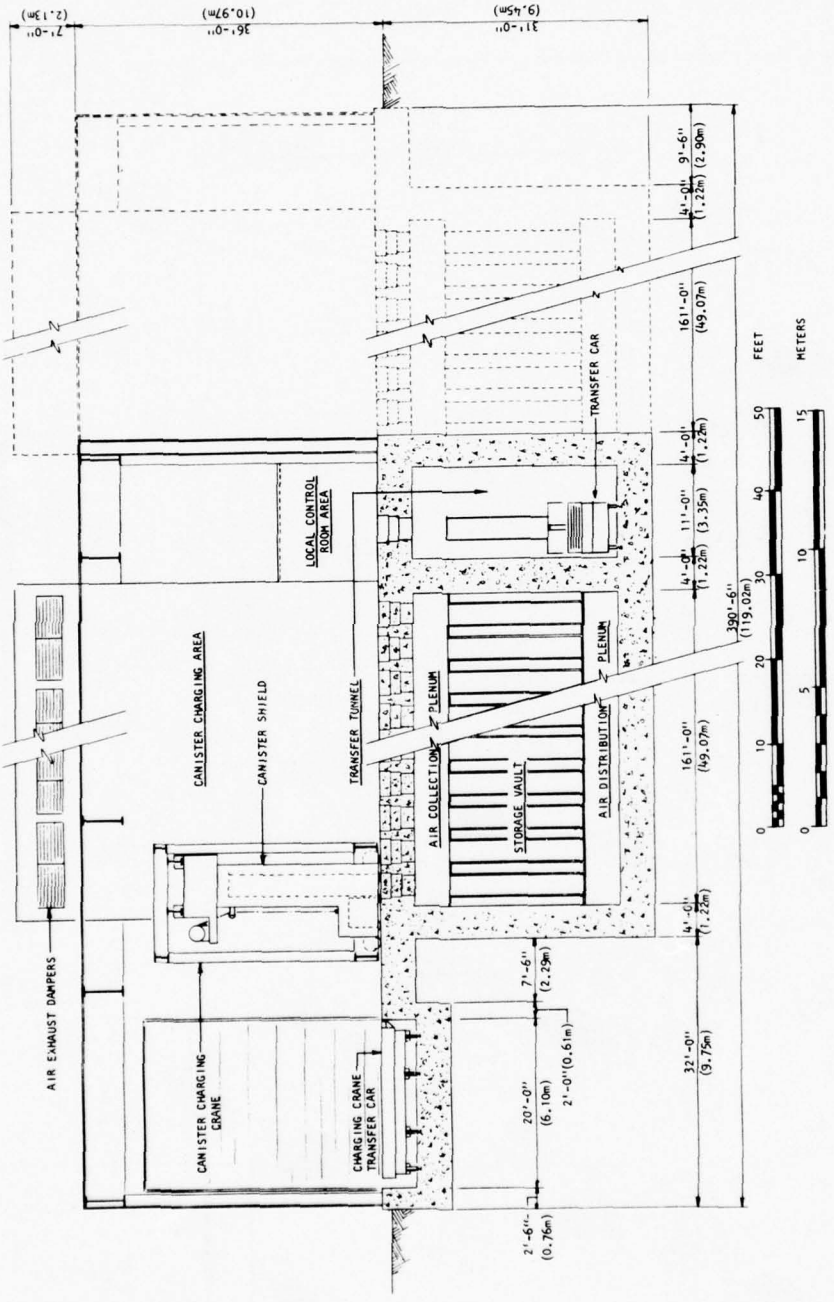


FIGURE 5.7.66. ACVSF Section A-A

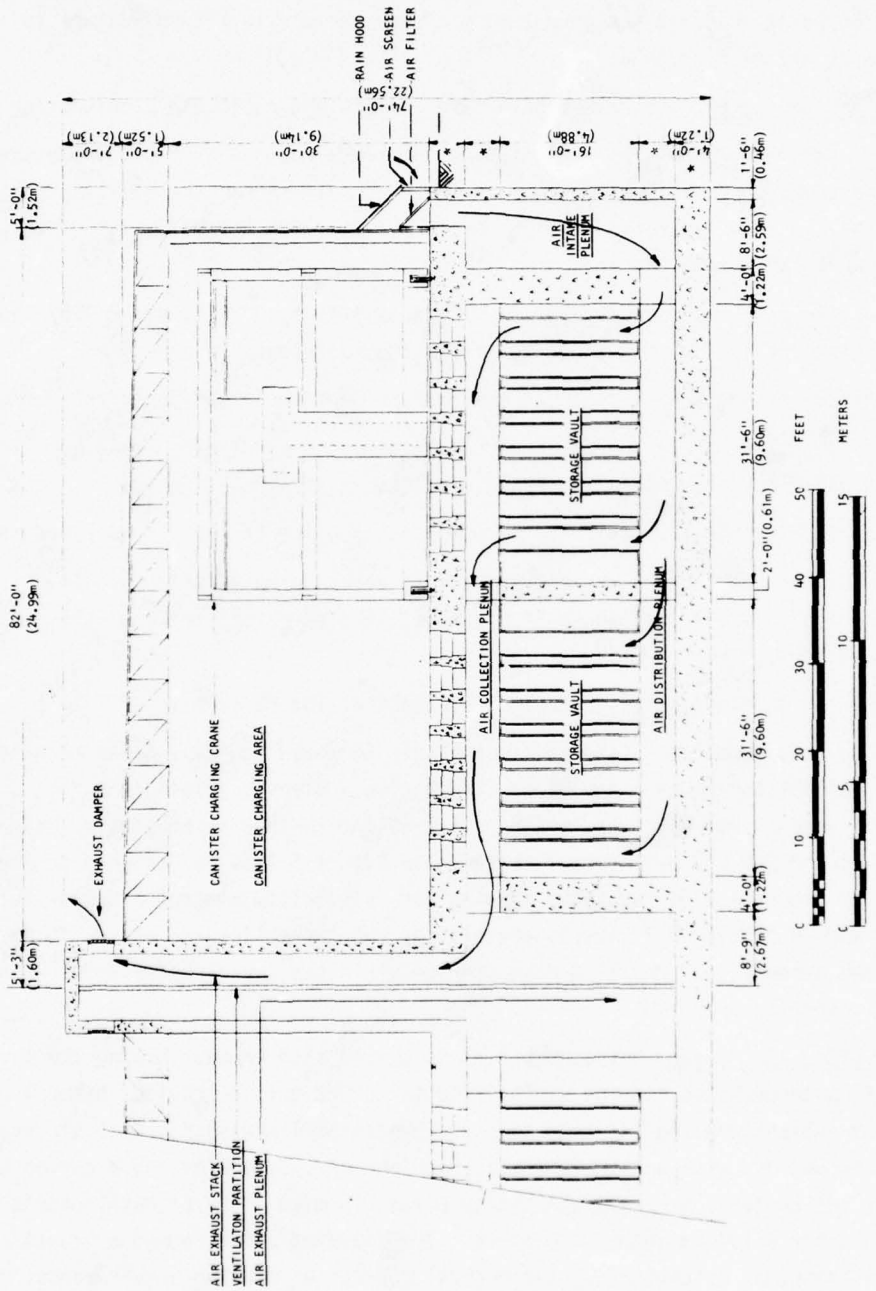


FIGURE 5.7.67. ACVSF Section B-B

The building superstructure, which encloses the vault storage plugs and crane traverse area, is standard commercial construction with structural steel framing and insulated metal panel walls and roofing. Air diversion tunnels and sand filters are Category I structures. The canister charging crane is Category I to minimize the possibility of damage to a fuel assembly as a result of a crane drop.

Systems and Equipment. Described below are systems and equipment provided for the ACVSF.

Packaged Fuel Transfer System. A motor-drawn, track-mounted cart which operates in an underground transfer tunnel moves packaged fuel assemblies from the adjacent facility to the ACVSF. The cart has two racks: one that carries four PWR assemblies and the second that carries nine BWR assemblies.

Container Charging and Storage Systems. Figures 5.7.65, 5.7.66, and 5.7.67 show the canister charging crane. The crane has the following features:

- It can handle either four individual PWR or nine individual BWR containers at one time.
- It has a special remotely-operated grapple assembly to handle the PWR assemblies; a second grapple device handles the BWR assemblies.
- The crane is electrically powered; the power is supplied through an overhead trolley wire.
- In each half of the storage vault there are three crane rails which are 11 m (36 ft) apart. A double track car, shown in Figure 5.7.65, moves the crane to the different track positions.
- The crane and shielding have an estimated weight of 163 MT (180 tons).

Each group of assemblies is stored (four singly packaged PWR assemblies or nine singly packaged BWR assemblies) under a removable shield plug. Sleeves joining the tube sheets receive these multiple assemblies, as shown in Figure 5.7.68 for the PWR assemblies. The spacing pattern for grouped PWR and BWR assemblies shown in Figure 5.7.69 is designed to meet the requirements of geometrically favorable spacing for criticality control. Spacer guides in the sleeves maintain 38 cm (15 in.) between centers for PWR assemblies and 25 cm (10 in.) between centers for BWR assemblies. One 2000 MTHM storage vault has capacity for 2690 PWR assemblies and 4030 BWR assemblies.

Vault Cooling Air Systems. Figure 5.7.67 is marked with arrows showing the path for cooling air flow through the storage vault. The structure design provides natural convective circulation of ambient cooling air over the self-heated fuel packages. Each storage module is divided into halves, with an air intake at each end of the modules and a common hot air exit stack at the center. Screened air intake ports minimize entry of dust, debris, rainwater, and birds and other wildlife into these ports. The louvered and screened exhausts are 11 m (36 ft) above grade, as determined by the natural convection cooling requirements. Effluent air flow may be diverted with exhaust air blowers through a tunnel to a sand filter. A baffle in the middle of the exhaust air stack permits diversion of one half of a storage module at a

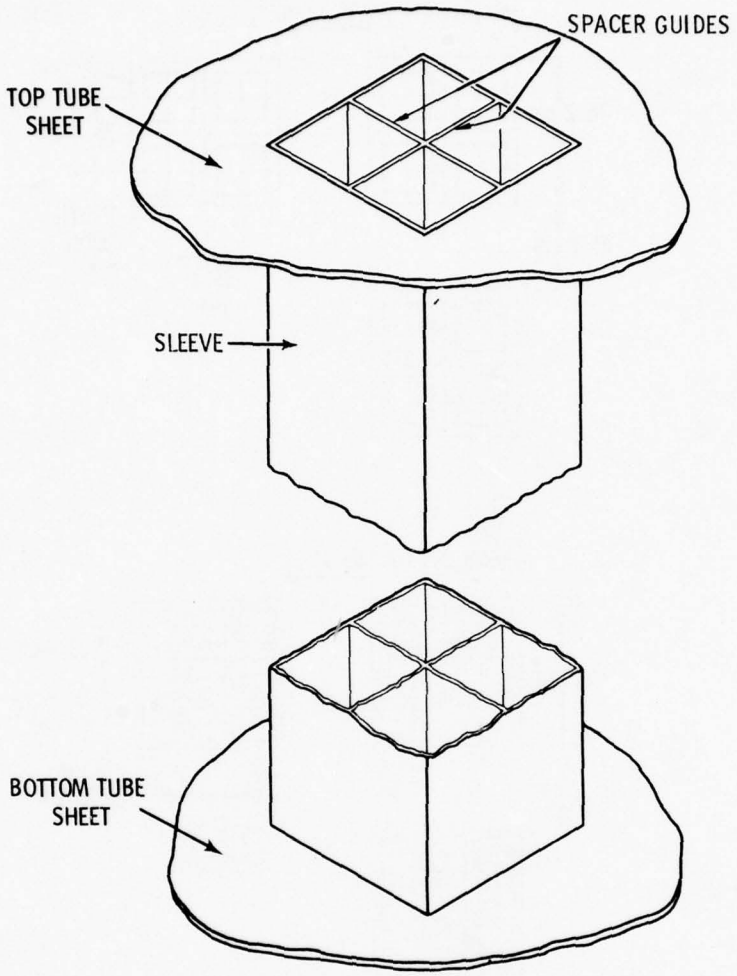


FIGURE 5.7.68. Sleeve for Packaged PWR Fuel

time. A plenum chamber 1.2 m (4 ft) deep at the bottom of each vault distributes inlet air to each storage position. A plenum chamber at the top of each vault collects the air from each heated position and directs it into the stack. The two plenums are connected by the sleeves where the fuel packages are stored.

Air sampling probes in each stack section detect the presence of helium or radioactivity in the exit air.

Emergency Sand Filters and Blower Station. The design and construction features of the two sand filters are described in Section 4.11.2. Each can handle the cooling air flow for one half of a 2000 MTHM storage module. Since these filters are required only in the unexpected event of storage container failure, each is considered sufficient for emergency service for

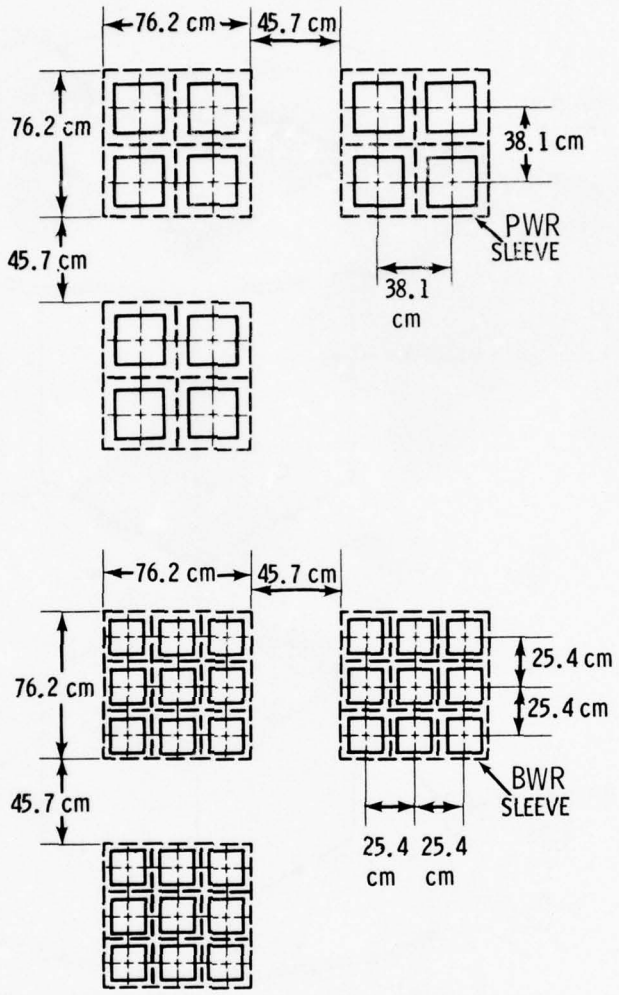


FIGURE 5.7.69. Spacing of Boiling Water Reactor and Pressurized Water Reactor Assemblies

five 2000 MTHM storage modules. Because of the decreasing heat load of fission product decay, this represents a filter capacity of at least 12% of the total cooling air capacity. The air flow capacity of each sand filter installation is 2125 m^3/min (75,000 ft^3/min).

Superstructure Ventilation System. The superstructure housing the storage modules and the canister charging crane is primarily for weather protection. It also keeps storm water from entering the concrete storage plugs. The building is not air conditioned. Gravity exhaust ventilators change the air once each hour. Space heaters maintain a winter temperature above 16°C (60°F) in the module being filled.

Shielding and Remote Handling Equipment. Personnel shielding in the facility operating area is provided by 1.5 m (5 ft) of reinforced concrete, or its equivalent, which reduces personnel exposure to less than 1 mrem/hr during routine operations. At structure openings, such as the air stack outlets and air inlets, radiation levels may be significantly higher than in the operating area. Direct shielding, radiation bends, and restricted personnel access limit personnel exposure in these higher radiation areas.

5.7.6.5 Operating and Maintenance Requirements for the Facility for Air-Cooled Vault Storage of Packaged Spent Fuel

The reference facility operates 24 hours a day, 7 days a week. Normal activities include continuous monitoring of cooling air exhaust, transport of fuel canisters between the storage facility and the adjacent fuel packaging or receiving facility, charging and removing spent fuel canisters in the storage vault area, and general facility maintenance.

Handling. Most reference facility activity is handling spent fuel canisters. This is done remotely by control room operators whose dose rates are less than 1 mrem/hr. Infrequently, personnel may be exposed to higher dose rates during certain operations and maintenance activities; however, dose rates are controlled by semiremote and shadow shielding techniques to well within the requirements of Title 10, Part 20 Code of Federal Regulations.[8]

Staffing. The estimated facility staffing requirements are shown in Table 5.7.63.

TABLE 5.7.63. Staffing Requirements for Air-Cooled Vault Storage of Packaged Spent Fuel

Job Description	Personnel Required, man-yr/yr
Operators	9
Maintenance	9
Radiation monitors	5

Supplies and Utilities. No supplies are needed for normal operation of the facility. Utility requirements are shown in Table 5.7.64.

TABLE 5.7.64. Utility Requirements for Air-Cooled Storage of Packaged Spent Fuel

Utility	Use Rate	Annual Requirement
Electricity	600 kW	5.3×10^6 kWh
Gasoline	0.11 m^3/day	40 m^3

Hazardous Materials. Spent nuclear fuel is the only hazardous material handled routinely during facility operations. Occasionally some hazardous chemical decontamination agents, such as nitric acid or organics, may be used.

5.7.6.6 Secondary Radioactive Wastes for the Facility for Air-Cooled Vault Storage of Packaged Spent Fuel

Secondary radioactive wastes are generated from materials, facilities, and equipment that are exposed to nuisance radionuclide surface contamination that may exist on spent fuel package surfaces. Rare package failures may also cause some radionuclide contamination. Any significant contamination requires clean up with decontaminating agents; these are stabilized for offsite shipment. The estimated quantity and activity level of secondary wastes are shown in Table 5.7.65.

TABLE 5.7.65. Secondary Radioactive Wastes from the Facility for Air-Cooled Vault Storage of Packaged Spent Fuel

Description	Volume, m^3/yr	Radioactivity Factors[a]		
		Activation Products	Fission Products	Actinides
Combustible and compactable waste	170	All 1×10^{-9}	All 1×10^{-11}	0
Wet wastes	5	All 1×10^{-7}	Cs 4×10^{-8} All others 1×10^{-9}	0
Failed equipment and noncombustible waste	10	All 1×10^{-10}	All 1×10^{-12}	0

a. Fraction of input activity in secondary wastes. For input use column 3 of Table 5.7.2 and 2000 MTHM/yr.

5.7.6.7 Emissions from the Facility for Air-Cooled Vault Storage of Packaged Spent Fuel

Estimated emissions from the reference facility operation are described in Table 5.7.66. Radionuclide releases are assumed to be negligible since the low release rates occurring during storage of unpackaged fuel (Section 5.7.1) would be further reduced by at least several orders of magnitude by containment of the fuel elements in high integrity packages.

5.7.6.8 Decommissioning Considerations for the Facility for Air-Cooled Vault Storage of Packaged Spent Fuel

Since decontamination of the facility occurs as needed throughout its life, the residual activity at the time of decommissioning is expected to be small (<1 Ci). Decommissioning plans are incorporated into the facility design. A quality assurance program is employed both during facility design and during operation. Removable surfaces are applied to structures which are susceptible to hard-to-remove radionuclide contamination; monitoring and recording devices are provided to determine contamination levels; removal and retirement ease are considered when selecting all materials and equipment for the facility.

TABLE 5.7.66. Emissions from the Facility for Air-Cooled Vault Storage of Packaged Spent Fuel

Emissions	Description	Annual Quantity	Radioactivity Release to Atmosphere
Gaseous	Facility air	9.8×10^9 m^3	Negligible
	Minor accident integrated annual release		None identified
Other	Heat	$\leq 2.0 \times 10^5$ MW-hr (6.6×10^{11} BTU)	

5.7.6.9 Postulated Accidents for the Facility for Air-Cooled Vault Storage of Packaged Spent Fuel

Safe storage with an air-cooled vault facility is accomplished by providing back-up emergency systems, such as monitoring devices and exhaust air sand filters, and having a skilled staff which is well trained in safety and confinement systems operations during normal and emergency facility operation.

Postulated minor and moderate accidents are presented in Tables 5.7.67 and 5.7.68. No accidents that could be classified as severe accidents could be realistically postulated for this technology.

TABLE 5.7.67. Minor Accidents for Air-Cooled Vault Storage of Packaged Spent Fuel

Accident Number and Description	Sequence of Events	Safety System	Release
5.7.30 — Loss of cooling air flow.	1. Debris plugs air intake to storage vault. 2. Stored fuel begins to heat up. 3. Temperature alarms alert operating personnel. 4. Blockage is removed and normal air flow is restored.	1. Screens protect intake and exhaust ports. 2. Redundant temperature sensors and alarms. 3. Personnel trained to take appropriate action to assure fuel cooling.	None
5.7.31 — Flooding of storage vault.	1. Surface runoff enters storage vault. 2. Alarm sounds. 3. Water is tested for activity and pumped to an evaporation pond. 4. Normal airflow resumes.	1. Runoff diversion system. 2. Level alarms provided. 3. Array subcritical when flooded. 4. Canister protects fuel.	None
5.7.32 — Dropped fuel rack in transfer tunnel or vault.	1. Rack grapple, grapple lifting cable, or cable winch fails when filled fuel rack is being moved to storage vault. 2. Filled rack falls to bottom of vault or transfer tunnel.	1. Overpack and rack designed to withstand such a fall without loss of integrity.	None

TABLE 5.7.68. Moderate Accidents for Air-Cooled Vault Storage of Packaged Spent Fuel

Accident Number and Description	Sequence of Events	Safety System	Release
5.7.33 – Packaged assembly fails in storage; expected frequency 5 x 10^{-5}/ MTHM-yr of storage.	1. Corrosion causes canister to fail in storage, releasing contained gases; also, one PWR rod has a pin hole leak. 2. Activity is detected in the vault exhaust air. 3. Failed element is located and removed to packaging facility for overpacking. 4. Facility is decontaminated.	1. Atmosphere controlled to minimize corrosion 2. Redundant helium and activity monitors. 3. Failed package detection system. 4. Emergency exhaust-air blowers and filters can be used if needed.	Assuming 6.5-yr old PWR fuel, the following are released over a 15 min period via the vault exhaust ports: ^{3}H = 5.6 x 10^{-3} Ci ^{14}C = 4.1 x 10^{-5} Ci ^{85}Kr = 3.5 Ci ^{129}I = 5.9 x 10^{-6} Ci All others = negligible

5.7.6.10 Costs for the Facility for Air-Cooled Vault Storage of Packaged Spent Fuel

Capital, operating, and levelized unit cost estimates have been made in mid-1976 dollars. A description of the bases, assumptions, and definitions used in the cost estimates is given in Section 3.8.

Capital Costs. The capital cost estimate for the air-cooled vault storage facility is shown in Tables 5.7.69, 5.7.70, 5.7.71, and 5.7.72. The initial construction, Phase I, is built at the same time as its adjacent fuel packaging or packaged fuel receiving facility. Construction includes the transfer tunnel from the adjacent facility, a 2000 MTHM storage vault module, a sand filter and blower (emergency ventilation) station with capacity to ventilate one-half of a storage module, and site preparation for incremental additions of one 2000 MTHM storage vault module each year for nine years. Ultimate storage capacity will be 20,000 MTHM. The reference facility would be built in 10 phases. Costs for Phase II through V are the same and are given in Table 5.7.70. For Phase VI, a second sand filter and blower station, capable of handling air diverted from one-half of a full storage module, is added. Phase VI costs are shown in Table 5.7.71. The costs for each of Phases VII through X are identical and are shown in Table 5.7.72.

Each estimate covers all capital costs resulting specifically from the addition of that facility component at the associated fuel packaging or receiving facility. All utilities are supplied from the fuel packaging or receiving facility. The air-cooled vault storage facility cost estimate also includes allowances for incremental additions to the associated facility for utilities supplied to the storage facility. No allocation of general costs is made to the storage facility for support services, such as laboratories, warehouses, administration office, maintenance shops, and so on.

TABLE 5.7.69. Capital Cost Estimate for Air-Cooled Vault Storage of Packaged Spent Fuel, Phase I - Initial Construction Including One 2000-MTHM Storage Module

	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		10	1,800	100	1,900
Buildings and structures		1,130	10,800	13,500	24,300
Bulk materials		80	800	900	1,700
Site improvements		40	600	500	1,100
Subtotal of direct site construction costs		1,260	14,000	15,000	29,000
Indirect site construction costs	330	250	5,500	7,300	12,800
Total field cost	330	1,510	19,500	22,300	41,800
Architect-engineer services					8,400
Subtotal					50,200
Owner's cost					15,100
Total facility cost					65,300
Estimate accuracy range					±30%

TABLE 5.7.70. Capital Cost Estimate for Air-Cooled Vault Storage of Packaged Spent Fuel, Phase II - Addition of One 2000-MTHM Storage Module

	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		10	900	100	1,000
Buildings and structures		940	9,900	11,300	21,200
Bulk materials		70	500	800	1,300
Site improvements					
Subtotal of direct site construction costs		1,020	11,300	12,200	23,500
Indirect site construction costs	270	200	4,500	5,900	10,400
Total field cost	270	1,220	15,800	18,100	33,900
Architect-engineer services					6,800
Subtotal					40,700
Owner's cost					12,300
Total facility cost					53,000
Estimate accuracy range					±30%

Note: 1. Phase II is to be ready to operate at start of the 2nd year.
2. Phases III through V will each have estimated additional capital costs equal to Phase II.

TABLE 5.7.71. Capital Cost Estimate for Air-Cooled Vault Storage of Packaged Spent Fuel, Phase VI - Addition of One 2000-MTHM Storage Module Including a Second Emergency Sand Filter

	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		10	1,200	100	1,300
Buildings and structures		950	9,700	11,500	21,200
Bulk materials		70	500	800	1,300
Site improvements					
Subtotal of direct site construction costs		1,030	11,400	12,400	23,500
Indirect site construction costs	270	210	4,600	6,000	10,600
Total field cost	270	1,240	16,000	18,400	34,400
Architect-engineer services					6,900
Subtotal					41,300
Owner's cost					12,400
Total facility cost					53,700
Estimate accuracy range					±30%

Note: Phase VI is to be ready to operate at start of sixth year.

TABLE 5.7.72. Capital Cost Estimate for Air-Cooled Vault Storage of Packaged Spent Fuel, Phase VII - Addition of One 2000-MTHM Storage Module

	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		10	800	100	900
Buildings and structures		760	8,800	9,200	18,000
Bulk materials		70	500	700	1,200
Site improvements					
Subtotal of direct site construction costs		840	10,100	10,000	20,100
Indirect site construction costs	220	170	3,700	4,800	8,500
Total field cost	220	1,010	13,800	14,800	28,600
Architect-engineer services					5,700
Subtotal					34,300
Owner's cost					10,300
Total facility cost					44,600
Estimate accuracy range					±30%

Note: 1. Phase VII is to be ready to operate at the start of the seventh year.
2. Phases VIII through X (eighth through tenth years) will each have estimated capital costs equal to Phase VII.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation with the exception of working capital. The cost of canisters and overpacks (which are included as part of the packaging facility's costs) are not included.

Operating Costs. The operating cost components for annual reference facility operation when receiving and storing 2000-MTHM/yr are shown in Table 5.7.73. Direct labor costs are based on manpower estimates given in Table 5.7.63. Process materials costs are negligible; the carbon steel canister costs are included in the packaging facility cost estimates. Annual maintenance materials costs are estimated at three percent of initial major equipment costs. Overhead and miscellaneous costs are estimated using the standard method described in Section 3.8.

TABLE 5.7.73. Operating Cost Estimate for Air-Cooled Vault Storage of Packaged Fuel

Cost Element	Annual Costs $1000s	
Direct labor	350	
Process materials	0	
Utilities	100	
Maintenance materials	60	
Overhead	410	
Miscellaneous	200	
Total	1120	+50% -25%

Levelized Unit Costs. Table 5.7.74 lists the total levelized unit cost as well as the capital and operating components. The cost calculations assume Federal ownership of the reference facility. The operating scenario is identical to the one discussed under levelized costs for packaged spent fuel water basin storage (Section 5.7.5). The effect of using round carbon steel canisters instead of rectangular canisters is discussed with the packaging facility costs, Section 5.7.3.10.

TABLE 5.7.74. Levelized Unit Cost Estimates Air-Cooled Vault Storage of Packaged Fuel

Cost Element	Unit Cost, *$/kg HM*	
Levelized capital charge	28.00	
Levelized operating charge	1.80	
Levelized total unit cost	29.80	±30%

5.7.6.11 Construction Requirements for the Facility for Air-Cooled Vault Storage of Packaged Spent Fuel

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The information that follows provides a basis for evaluating this impact.

Project Schedules and Construction Manpower. The initial phase construction of the storage facility occurs at the same time as the construction of the adjacent reference facility (see Section 5.7.3.11). The field labor force necessary for the initial (Phase I) construction of the ACVSF is estimated below:

	Man-hours, 1000s
Manual field labor	1510
Nonmanual field labor	330
Total field labor	1840

These construction man-hours are integrated with labor schedules for the associated reference facility.

The field labor force necessary for the yearly addition of one storage vault module is estimated below:

	Phases *II through V*,(a) 1000s of man-hours	Phases *VI through X*,(a) 1000s of man-hours
Manual field labor	1220	1010
Nonmanual field labor	270	220
Total field labor	1490	1230

a. Man-hours apply to each construction phase; i.e., each module.

The field labor force necessary for the Phase VI addition of one sand filter and blower installation only is estimated below:

	Man-hours, 1000s
Manual field labor	230
Nonmanual field labor	50
Total field labor	280

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the storage facility. Offsite costs are those for all services, equipment fabrication or assembly, and materials purchased elsewhere. The distribution of total costs in these categories is as shown below:

	Costs, $1000s			
	Phase I	Phase II through V	Phase VI only	Phase VII through X
Onsite	25,300	20,500	20,900	16,900
Offsite	40,000	32,500	32,800	27,700
Total	65,300	53,000	53,700	44,600

Site Requirements. The storage facility, constructed adjacent to one of the reference facilities (above any flood plain or credible flood levels), requires additional access roads and parking areas. Approximately 12.7 ha (31 acres) additional plant area is required at the associated reference facility site. This area provides for all ten storage modules, plus two sand filters. No additional area adjacent to the storage facility is required for construction storage, work yards, temporary buildings and labor parking.

Water. Water used during the initial (Phase I) construction period is approximately 25,400 m^3 (6.7 x 10^6 gal). During each of the construction Phases II through V, 20,400 m^3 (5.4 x 10^6 gal) is used. Phase VI, which includes the second sand filter, consumes approximately 20,800 m^3 (5.5 x 10^6 gal) and each of the construction Phases VII through X use approximately 16,700 m^3 (4.4 x 10^6 gal).

Construction Materials. Materials committed to the facility construction are:

	Phase I		Phase II[a]		Phase VI		Phase VII[a]	
Concrete	17,500 m^3	(22,900 yd^3)	13,800 m^3	(18,000 yd^3)	14,500 m^3	(18,900 yd^3)	10,700 m^3	(14,000 yd^3)
All Steel	4,600 MT	(5,100 tons)	3,900 MT	(4,300 tons)	4,100 MT	(4,500 tons)	3,400 MT	(3,800 tons)
Copper	7 MT	(8 tons)	3 MT	(3 tons)	3 MT	(3 tons)	3 MT	(3 tons)
Lead	10 MT	(11 tons)	--		--		--	
Lumber	1,200 m^3	(500 MFBM)	900 m^3	(370 MFBM)	940 m^3	(400 MFBM)	700 m^3	(300 MFBM)

a. Phases III through V quantities are the same as Phase II; Phases VIII through X quantities are the same as Phase VII.

Energy. Energy resources used during construction are:

	Phase I		Phase II[a]		Phase VI		Phase VII[a]	
Propane	208 m^3	(55,000 gal)	170 m^3	(45,000 gal)	170 m^3	(45,000 gal)	140 m^3	(37,000 gal)
Diesel fuel	2,080 m^3	(550,000 gal)	1,700 m^3	(450,000 gal)	1,700 m^3	(450,000 gal)	1,400 m^3	(369,000 gal)
Gasoline	1,400 m^3	(370,000 gal)	1,140 m^3	(300,000 gal)	1,140 m^3	(300,000 gal)	930 m^3	(246,000 gal)
Electricity								
Peak demand, kW	800		700		700		550	
Total consumption, kWh	1,050,000		850,000		860,000		700,000	

a. Phases III through V quantities are the same as Phase II; Phases VIII through X quantities are the same as Phase VII.

Transportation Requirements. No transportation requirements for the ACVSF have been identified other than those for the associated reference facility.

5.7.6.12. Effects of Fuel Cycles Options

Once Through Cycle. A long storage period prior to final repository availability may favor storing spent fuel in the packaged form.

Recycle of Uranium or Plutonium. A long storage period prior to a reprocessing decision or reprocessing plant availability may favor storing the spent fuel in the packaged form.

5.7.7 Dry Caisson Storage of Packaged Spent Fuel

A third alternative for extended storage of packaged spent fuel is referred to as the dry caisson concept. The caisson storage concept for packaged spent fuel uses soil conductivity to dissipate to the atmosphere the heat generated from spent fuel which is stored in a buried caisson. This fuel storage concept is similar to that being used at the Idaho National Engineering Laboratory[18] for storing Peach Bottom reactor fuel and to a technique[19] being used in Canada to store the Canadian reactor fuels. Although at this time the caisson approach is not being used for storage of commercial light water reactor fuels, it is a direct application of existing technology.[20]

5.7.7.1 Alternatives for Dry Caisson Storage of Packaged Spent Fuel

The caisson storage concept for packaged spent fuels is simple, but there are concept design variations based on the desired degree of safety, containment, isolation, retrievability, and economics. The concept described and analyzed in this section is based on the concept discussed in the Draft Environmental Statement, Handling and Storage of Spent Light Water Power Reactor Fuel.[20] The reference facility is designed to be licensed as a commercial spent fuels storage operation and thus would meet all of the safety and operational requirements of a licensed facility. Alternatives for the concept include: 1) positive sealing of the caisson top and bottom to assure radionuclide containment should the fuel and its package lose their integrity, 2) complete deep burial of the caisson to improve physical protection and prevent unauthorized access, 3) use of a variety of engineering design features which will achieve similar results including use of various construction materials, material thicknesses, corrosion protection systems, and array storage configurations. The primary effects of most concept variations would be on system costs and perhaps a minor improvement in concept safety. In general, further improvements in concept safety cost more and decrease the ease of spent fuel retrieval and system monitoring.

Double containment of the spent fuel is provided by single encapsulation of unfailed fuel assemblies (cladding is one barrier and the canister is the second) and by double encapsulation (overpacking) of any failed assemblies. A more conservative approach would be to doubly encapsulate all of the assemblies.

5.7.7.2 Design Basis for the Facility for Dry Caisson Storage of Packaged Spent Fuel

The following assumptions were made in the design of the reference facility:

- The storage facility is associated with the operation of a spent fuels packaging facility or an independent packaged spent fuel receiving facility. All support facilities and services, except for those peculiar to the storage operation, are provided by these associated facilities.
- The storage facility receives up to 2000 MTHM per year of packaged fuel elements (2690 PWR assemblies and 4020 BWR assemblies).

- The average exposure of the spent fuel is approximately 29,000 MWD/MTHM and it is aged at least 6.5 years from reactor discharge.
- The individually packaged spent fuel assemblies are placed in racks of 3 PWR or 6 BWR elements for placement in the caissons. Heat generation is initially about 1.5 to 2 kW per caisson.
- The initial construction module stores 2,000 MTHM of spent fuel in 1570 caisson units. Additional modules will be built as required until the facility reaches reference storage capacity of 20,000 MTHM or 15,700 caissons.
- The facility is designed for 100-yr storage capability, although the use period is expected to be significantly less. After storage, the packaged spent fuel is retrieved for shipment to a repository or reprocessing facility.
- The fuel elements are easily retrieved from the caissons.
- The caisson is designed so that its atmosphere may be monitored and sampled periodically.
- Operating equipment is designed to prevent excessive radiation exposure.

5.7.7.3 Operation of the Facility for Dry Caisson Storage of Packaged Spent Fuel

The dry caisson storage facility (DCSF) operation includes spent fuel transfer from the adjacent packaging or receiving facility to the storage facility, spent fuel movement to and placement in the caissons, filled caisson and storage area monitoring, and spent fuel removal from the caisson. Should any fuel package failure occur during these operations, the package is returned to the packaging or receiving facility for inspection and repackaging or overpacking if necessary. Package failure is considered a highly unlikely event. A schematic flowsheet of the operations at this facility is shown in Figure 5.7.70.

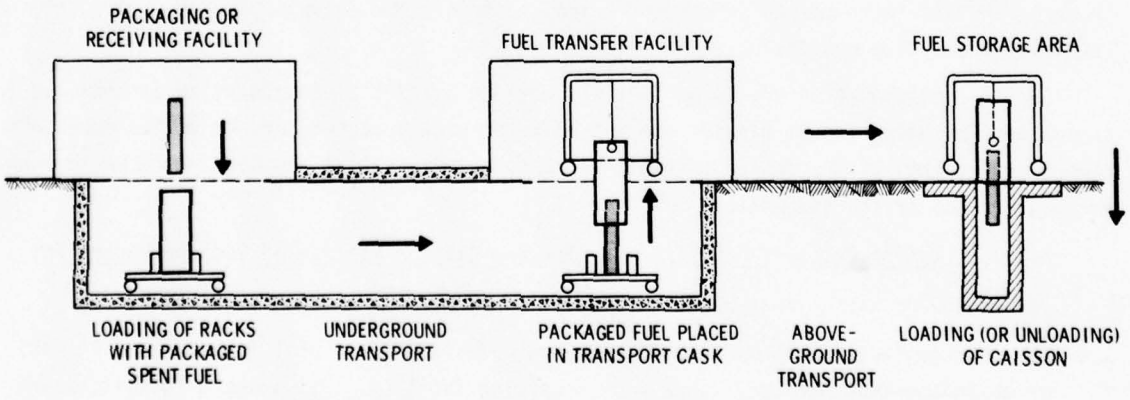


FIGURE 5.7.70. Schematic Flowsheet for the DCSF

At the adjacent fuel packaging facility or packaged fuel receiving facility, the packaged spent fuel is placed in either a BWR or PWR fuel assembly rack. The spent fuel is then transported on a dolly through an underground tunnel to the fuel transfer facility where the filled storage rack is lifted into the transport shielding cask. A self-propelled gantry crane transports the entire unit to a caisson and inserts it into the caisson. Then the caisson is closed with a concrete plug. Retrieval procedures are the reverse of the caisson loading procedures.

Air samples are periodically taken from the caisson interior to determine if there are any radionuclide leaks from the packages. Also, continuously operating area monitors are placed in the storage area to detect any airborne leakage from the caissons. An alternative to these monitors would be to continuously monitor each caisson (which could be accomplished with the present caisson design). Should monitoring detect a package failure, the package would be removed from the caisson and returned to the packaging or receiving facility for overpacking. Special precautions are taken during package removal to prevent the spread of radionuclides. These precautions include placing a temporary structure over the caisson and transporter and evacuating the caisson through a controlled ventillation system. A drainage system is provided for the storage area. Effluent is collected and monitored in two retention ponds which allow for decontamination of the effluent if required.

5.7.7.4 Description of the Facility for Dry Caisson Storage of Packaged Spent Fuel

The spent fuel storage facility consists of a transfer facility and an array of buried caissons which contain the spent packaged fuel. The facility is enclosed in a security fenced area. The caissons are arranged in 10 rectangular arrays, and each section is separated by roads and drainage systems. The overall facility plot plan is shown in Figure 5.7.71.

General Facility Arrangement. The DCSF consists of two main facilities: the fuel transfer facility (FTF), where the spent fuel is transferred to the fuel cask, and the fuel storage area (FSA), where the spent fuel is stored. The DCSF is located adjacent to either a spent fuel packaging facility or a packaged fuel receiving facility, as indicated in Figure 5.7.71.

The DCSF can receive and store packaged fuel elements at a rate of 2000 MTHM per year (2690 PWR assemblies and 4030 BWR assemblies). This requires approximately 1570 caissons per year, 900 for PWR assemblies and 670 for BWR assemblies. The actual design capacity is 1584 caissons per year. All caissons are identical and can store either PWR or BWR fuel. The reference FSA is divided into ten sections. Each can store 2000 MTHM. Figure 5.7.72 is the plot plan for Phase I, which provides storage for 2000 MTHM of spent fuel. The area enclosed within the fence represents the first year land commitment to storage and the area dedicated to construction of the next year's storage. Figures 5.7.73 and 5.7.74 show details of the FTF, a steel building that houses the fuel rack receiving and storage areas, the fuel transfer station, and the administrative and personnel area. A 3 ton overhead bridge crane serves the receiving and storage areas.

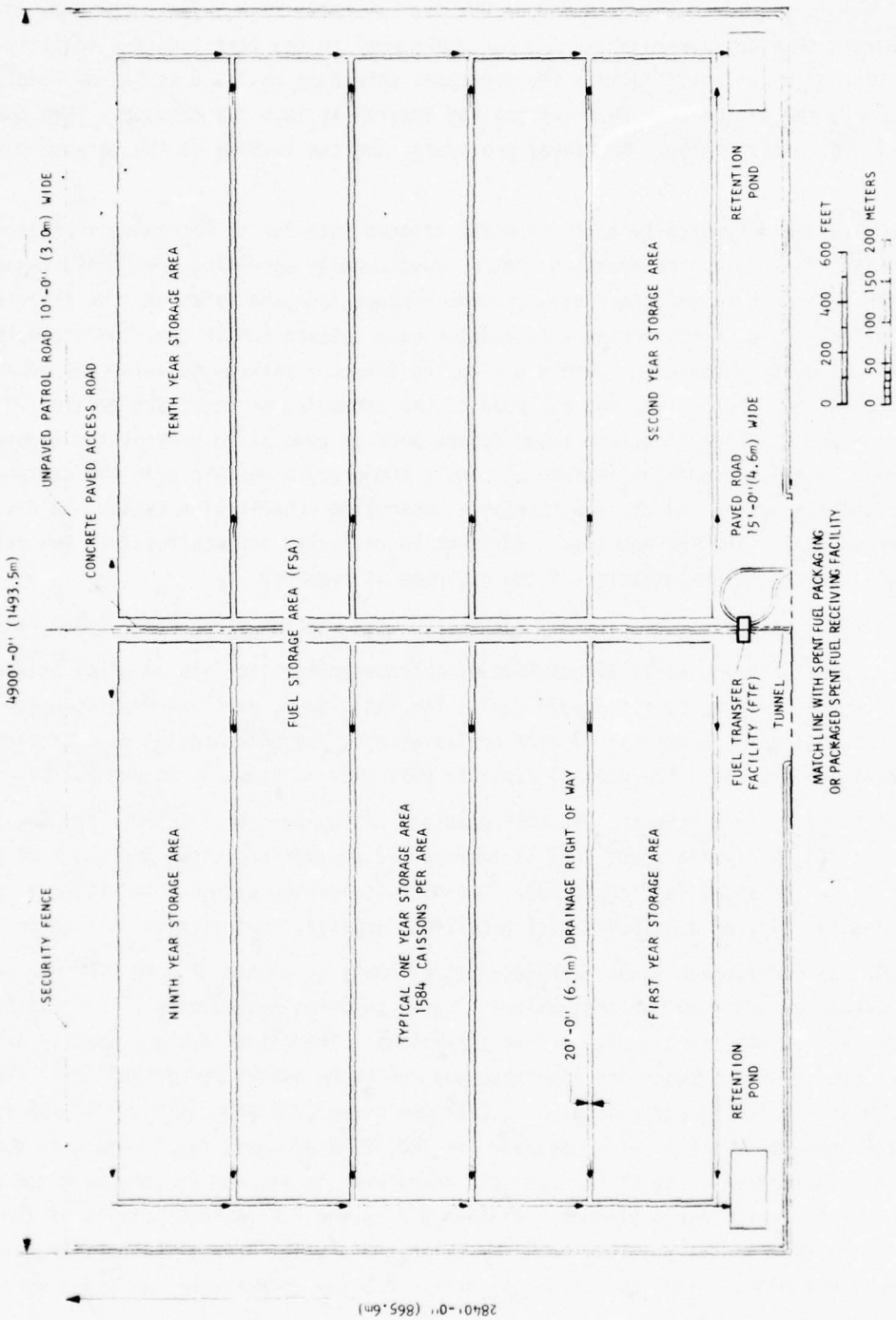


FIGURE 5.7.71. Plot Plan for the DCSF

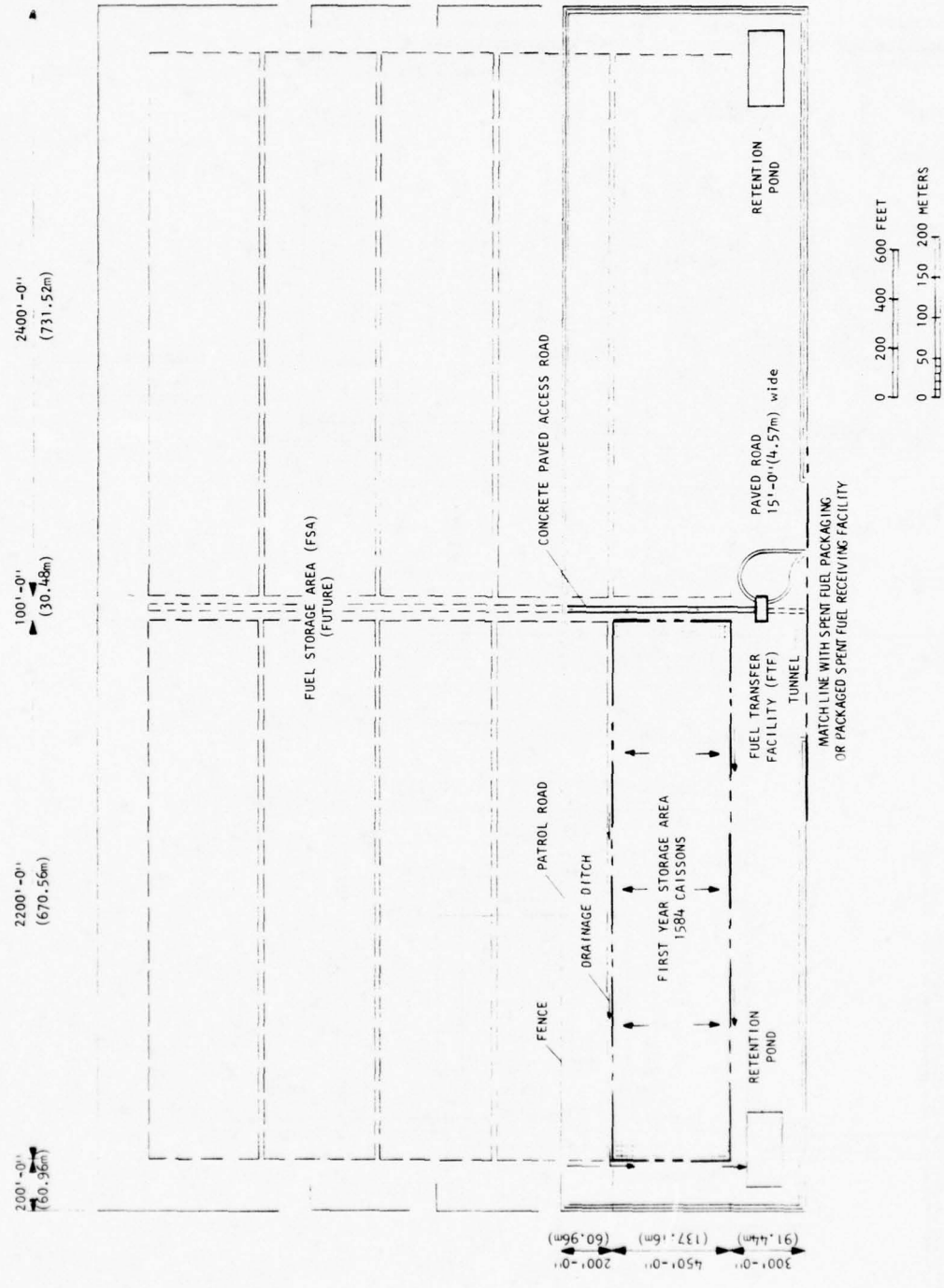


FIGURE 5.7.72. DCSF Phase 1 Plot Plan

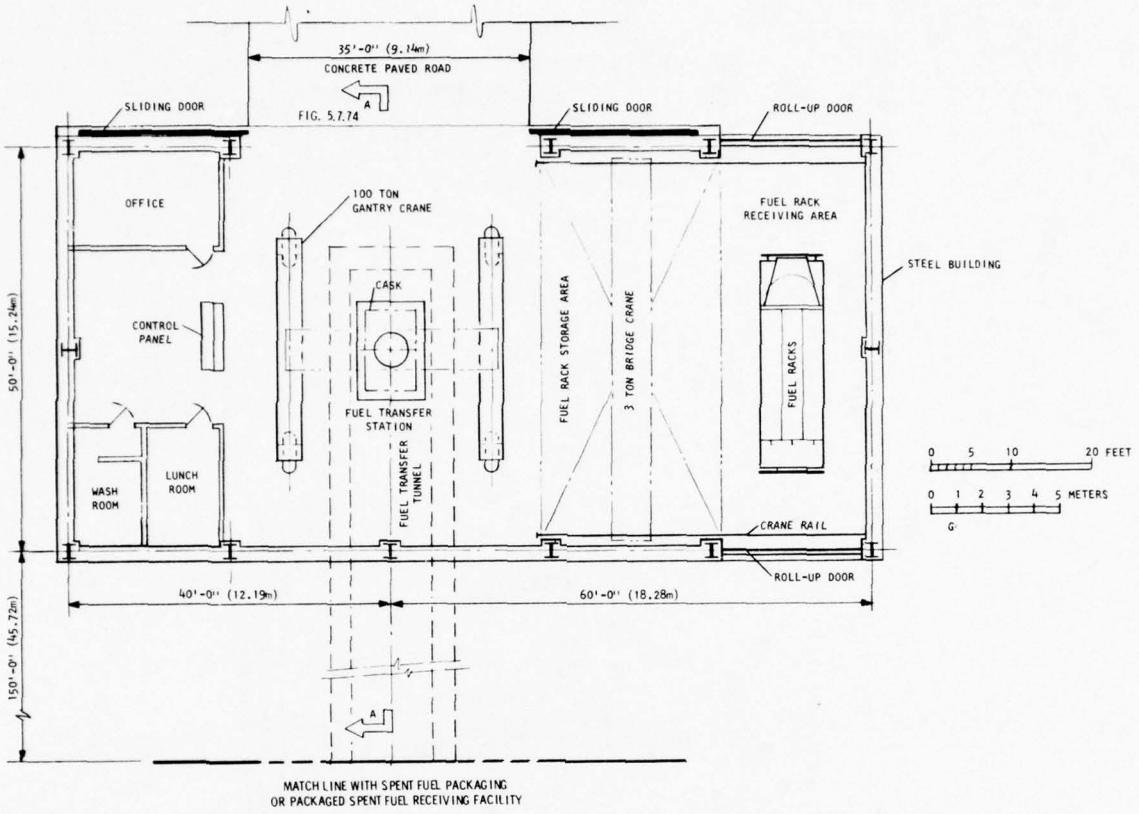


FIGURE 5.7.73. DCSF, Fuel Transfer Facility Plan

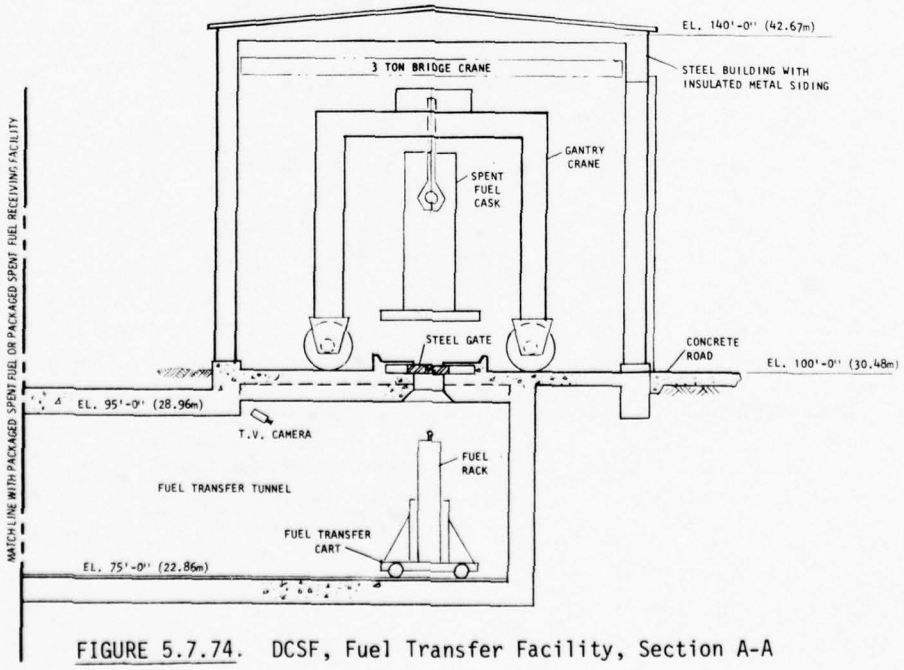


FIGURE 5.7.74. DCSF, Fuel Transfer Facility, Section A-A

The FSA extends beyond the FTF and, when completed, consists of 10 storage areas located at each side of a 10.7 m (35 ft)-wide concrete paved road. Each storage area is drained independently with surface ditches, which connect to the retention pond where run-off is monitored before release.

Structures. The facility components that surround and protect the fuel assemblies are designed as Category I structures. Structures which are not essential to fuel safety are of commercial construction quality. Category I structures are the fuel transfer tunnel, fuel cask, and storage caissons. Commercial construction structures are the steel building, the overhead bridge crane, and the gantry crane.

Systems and Equipment. New empty racks are stored at the FTF. The racks are moved to the associated facility where they are loaded with fuel and transferred to the cask for transportation to the FSA.

Fuel Rack Receiving and Storage. New racks, shown in Figure 5.7.75 are delivered by truck carrier to a drive-through bay located at one end of the FTF. The overhead bridge crane unloads the racks from the truck and stores them vertically in holding rails at the storage area.

The crane transfers the racks from storage through the floor hatch into the transfer cart, where they are moved to the associated facility for fuel loading. Cart operation is controlled from the associated facility and the FTF with the aid of closed circuit television and a communication system.

Fuel Cask Loading. The fuel cask loading system includes the fuel cask, fuel loading station, and the gantry crane. The fuel cask is a cylindrical shielded container which has a bifurcating gate at its bottom to allow the bottom loading and unloading of fuel racks. The hoisting equipment which handles the racks is attached to the top of the cask. The cask is made of structural plates separated by lead shielding. The interior surface of the cask cavity is stainless steel and the exterior is carbon steel painted with an epoxy coating. The cask, which is permanently attached to the gantry crane with a steel yoke secured to side trunnions, is raised and lowered by hydraulic cylinders that are part of the gantry crane system.

Spent fuel transfer to the cask is done at the fuel loading station, which is located above the fuel transfer tunnel. The fuel loading station matches the cask base and centers the cask cavity over a hatch in the floor. The hatch has mechanically-operated, horizontally-sliding shielding gates, which provide protection from the radiation of the racked spent fuel in the tunnel.

After the gantry crane has placed the cask on top of the floor hatch, the fuel racks are transferred to the cask in the following manner:

- The cask and hatch shielding gates are opened.
- The fuel rack is lifted into the cask cavity using cask hoisting equipment and a remotely operated grapple.

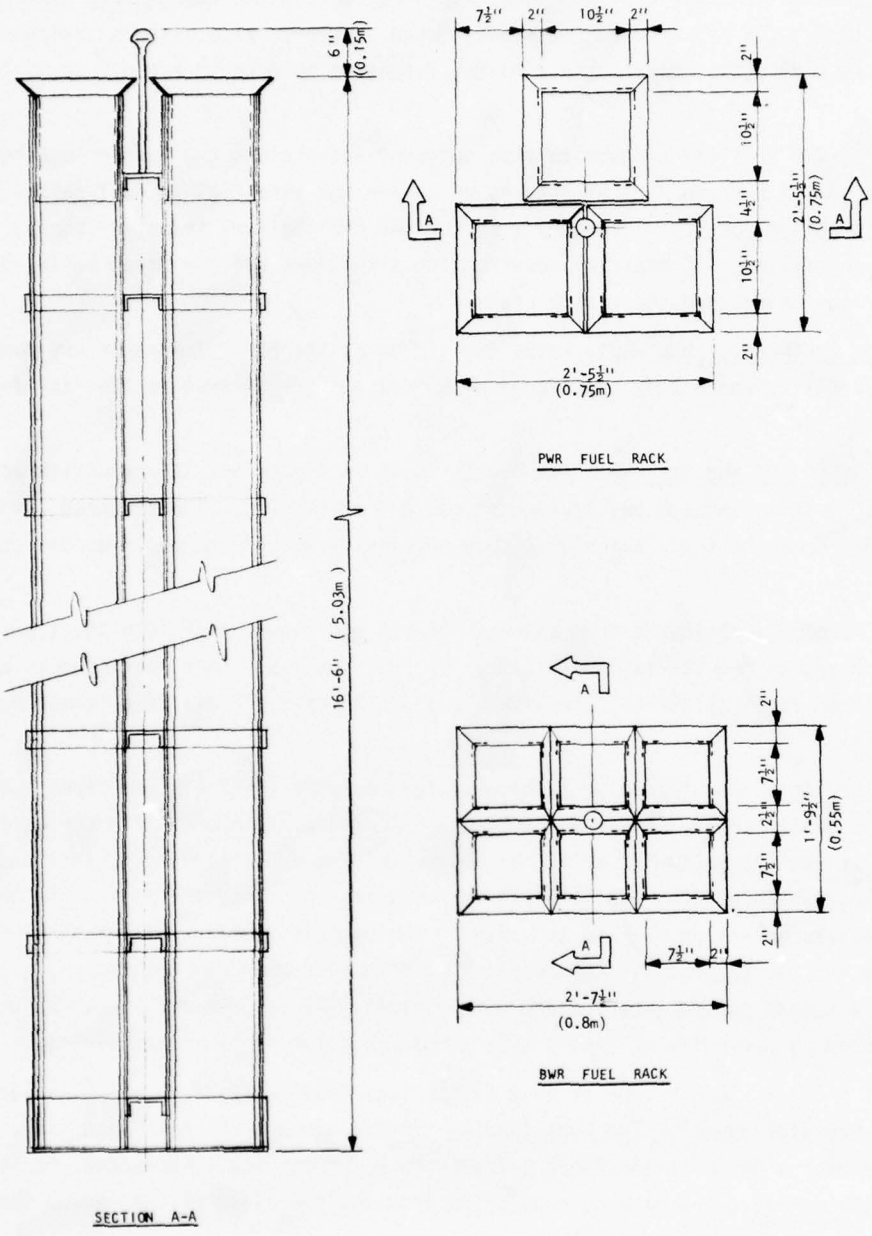


FIGURE 5.7.75. DCSF Fuel Rack Detail

- The cask and hatch shielding gates are closed.
- The cask is lifted from the floor and transported to the storage area with the gantry crane.

The gantry crane is a self-propelled. diesel-powered vehicle which rides on pneumatic tires. It is capable of carrying a 100-ton load. The operator's cab is mounted on the side frame of the crane.

The cask is supported vertically from the upper traveling bridge and horizontally by removable struts which are attached to the gantry frame to prevent excessive lateral movement of the cask while in transit. The distances between the crane tires and the wheel base are both 7.6 m (25 ft), which improves crane stability and allows the crane to straddle the caisson rows, which are located on a 7.6 m (25 ft) pitch.

Caisson. Figure 5.7.76 shows details of the caisson construction. Carbon steel pipe caissons are placed in drilled holes and concrete is poured between the pipe and the soil for corrosion protection. A precast concrete collar and matching shielding plug are placed on top of the caisson, and a concrete slab is poured around each hole as a foundation for the spent fuel transfer cask.

The caisson storage of packaged spent fuel is completely passive. The amount of generated fuel heat in the rack is limited to 1.5 to 2 kW. This heat limitation is based on the ability of the caisson construction materials to maintain their integrity under thermal conditions encountered during storage. The heat generated from the fuel is primarily radiated to the caisson walls and then conducted through the ground and caisson components to the earth's surface where it is dissipated to the atmosphere. Temperature values which may be attained in the caisson storage system are shown in Figure 5.7.77.[20]

Fuel Cask Unloading. The selected storage caisson is prepared to receive the fuel assemblies as described below.

A light duty mobile crane is used to place a fuel transfer platform (FTP) on the concrete slab around the caisson. The FTP, a steel frame which houses one bifurcating, horizontally-sliding shielding gate, aligns the cask cavity with the caisson and facilitates fuel delivery. The gate provides personnel protection from radiation when the cask is removed after emplacement of a loaded rack.

The same light duty mobile crane removes the shielding plug and places it in a predetermined location for future use.

The cask-carrying gantry crane is then positioned on top of the FTP above the open caisson. After the cask struts are removed and position adjustments are made, the cask is lowered onto the top of the FTP, as shown in Figure 5.7.78. The spent fuel is then transferred in the following manner:

- The shielding gates on the cask and FTP are opened.
- The cask hoisting equipment and the grapple lower the fuel rack into the caisson.
- The grapple is retrieved and the shielding gate on the FTP and cask are closed.
- The cask is lifted off the FTP and moved away from the caisson area. Struts are attached to the crane frame again, and the crane is returned to the FTF for the next trip to the FSA.
- The light duty crane places the shielding plug on top of the FTP.

- Temporary shielding is placed around the plug to absorb the radiation that originates in the fuel and scatters from the plug.
- The FTP gate is opened and the plug is lowered into the caisson.

Monitoring. The caisson internal atmosphere is monitored to detect airborne contamination, but because the spent fuel is packaged in sealed steel canisters, contamination is unlikely to occur inside the caisson.

The shielding plug is penetrated with a monitoring tube that is sealed with a valve. A beta-gamma monitor can be connected to this valve and air samples of the caisson can be taken and monitored periodically or continuously.

Shielding and Remote Handling Equipment. Radiation shielding of the packaged spent fuel is required at all times. During remote underground transport between the adjacent facility and the fuel transport facility, the transfer tunnel concrete walls and surrounding soil provide shielding. The transport cask, which moves the fuel from the FTF to the spent fuel storage area, is shielded to provide personnel radiation protection. The 1.2 m thick caisson concrete plug and the surrounding concrete and soil reduce radiation to <10 mrem/hr above the caisson. This dose rate is acceptable because the area above the caissons is not normally occupied by operating personnel. Fuel placement and removal operations from the caisson are performed semiremotely to limit operating personnel exposures to within acceptable limits.

5.7.7.5 Operating and Maintenance Requirements for the Facility for Dry Caisson Storage of Packaged Spent Fuel

The reference facility is designed to operate 24 hr a day, 7 days a week. It is estimated that a gantry crane takes 2 hours to make a round trip for canister assembly placement, and only day and swing shift on a 5 day week would be necessary for assembly placement, although the storage area would be monitored 24 hr a day. If a second gantry crane were available for part-time use, only the day shift would be needed for assembly placement. Normal activities include spent fuel receiving, placement, and removal; area monitoring; and storage area maintenance.

Operations and Maintenance. The normal operations and maintenance procedures for the reference facility are relatively simple. Packaged spent fuel is transported from the adjacent facility to the FTF by remote operation. Spent fuel is moved with semiremote techniques from the FTF to the FSA and for caisson loading/unloading. All other maintenance, such as area patrolling, caisson building, and yard upkeep, are done manually. The dose rate for normal activities is maintained below 1 mrem/hr. Infrequent operations may result in higher dose rates to personnel, but these rates are kept to well within the requirements of Title 10, Part 20 of the Code of Federal Regulations [8]

Staffing. Estimated manpower requirements for normal operation are presented in Table 5.7.75.

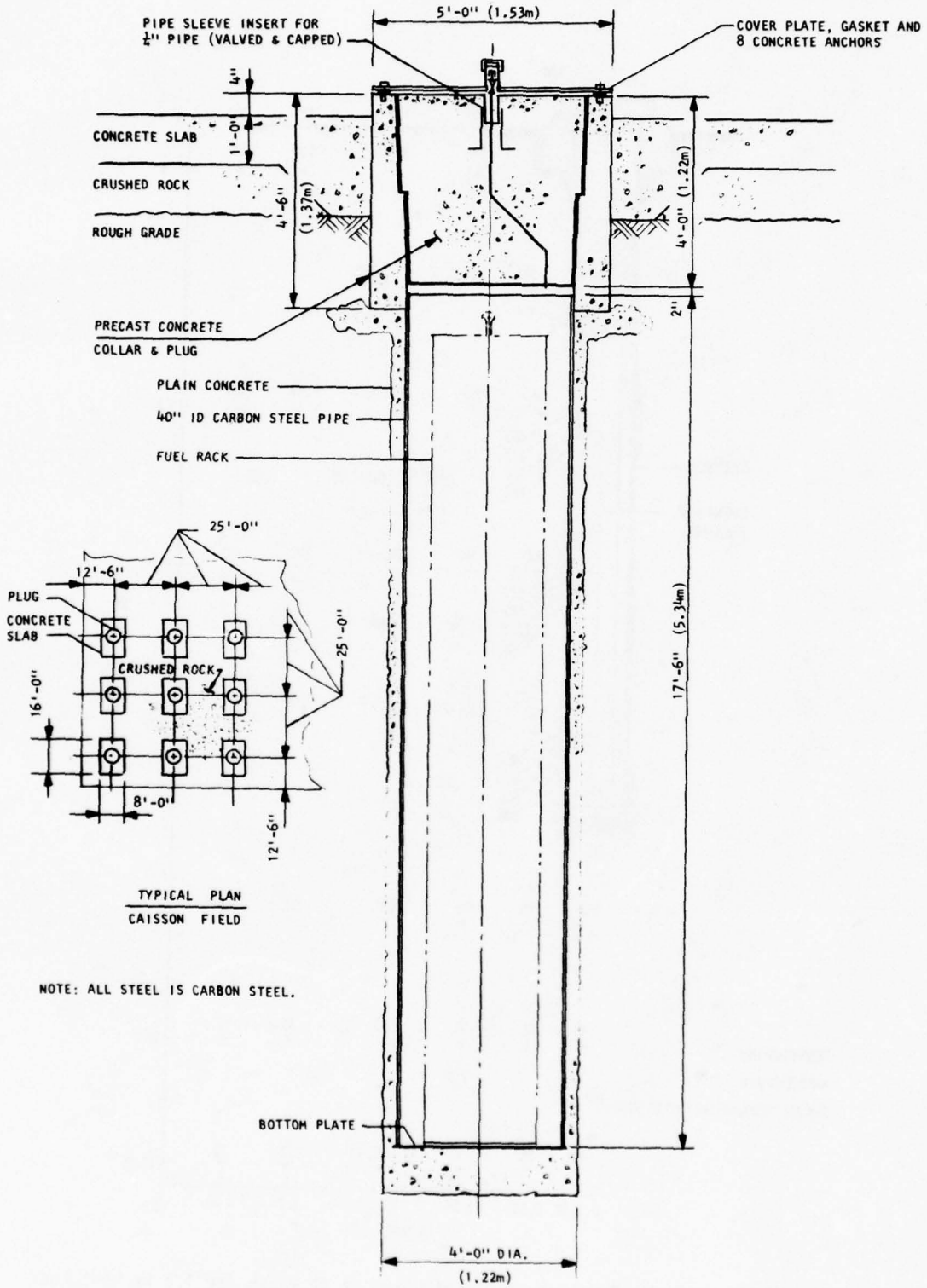


FIGURE 5.7.76. DCSF Caisson, Detail

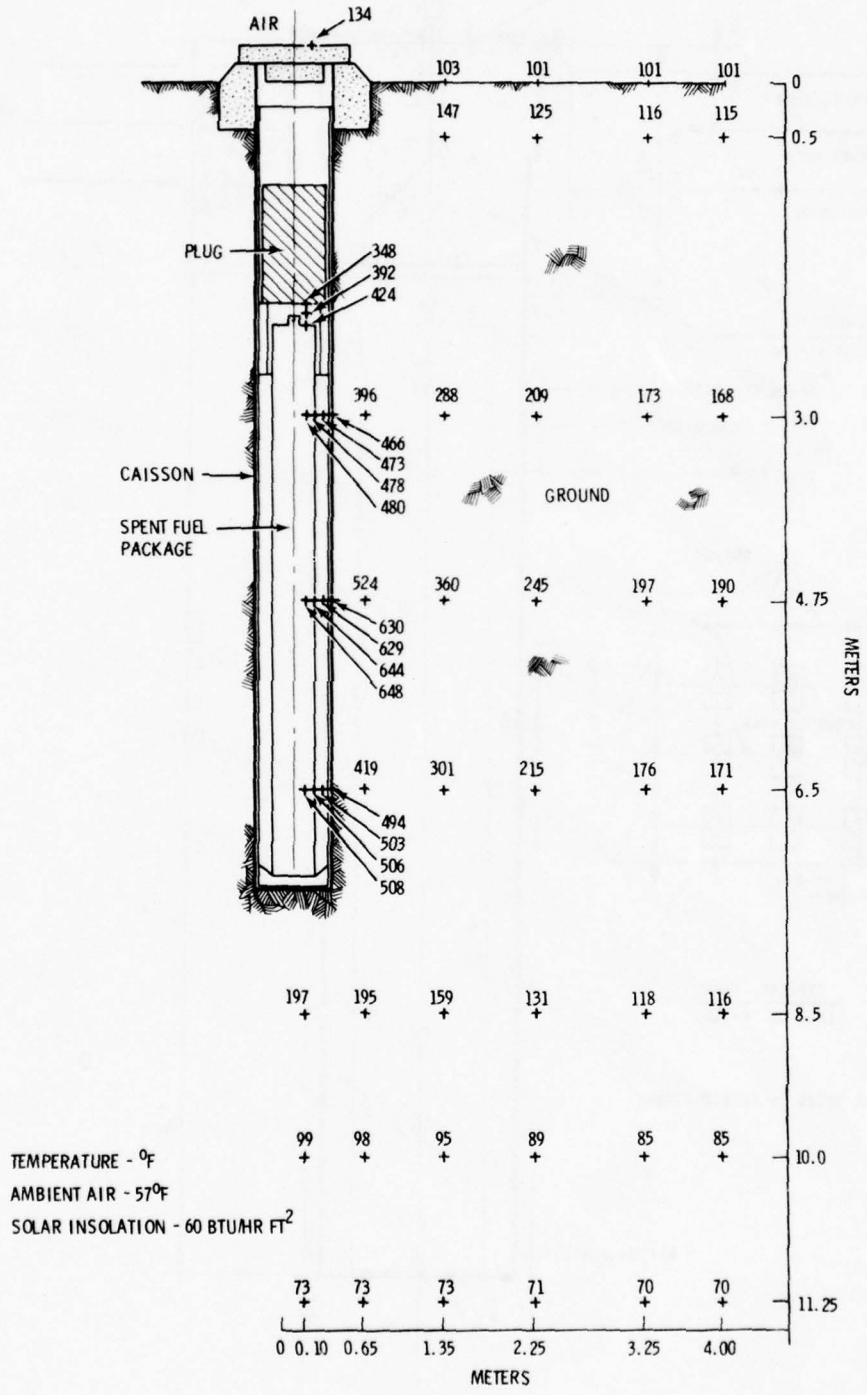


FIGURE 5.7.77. Caisson Temperature Distribution at 42 Weeks for 1.5 kW Heat Load

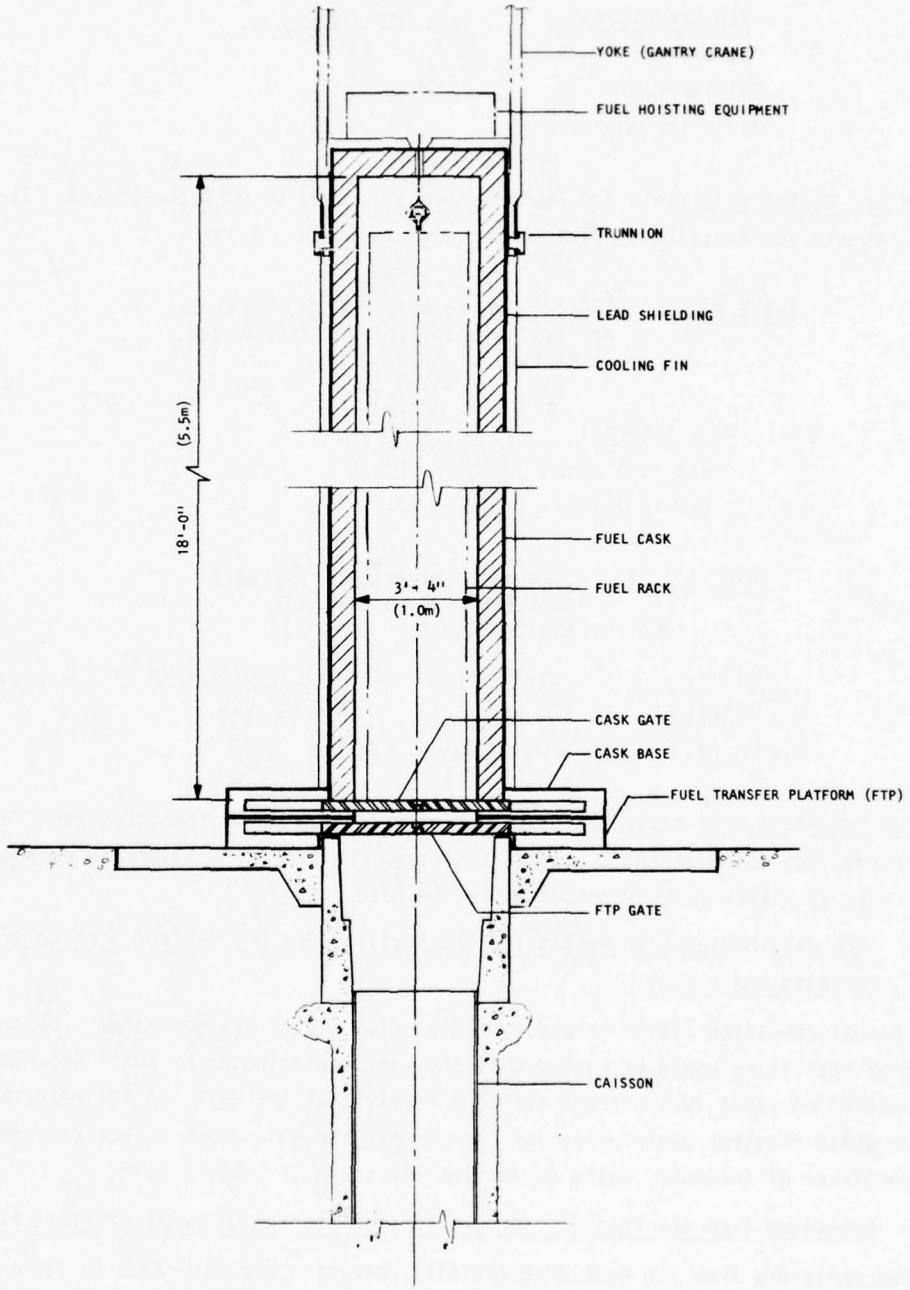


FIGURE 5.7.78. DCSF Fuel Transfer Detail

TABLE 5.7.75. Staffing Requirements for the Facility for Dry Caisson Storage of Packaged Spent Fuel

Job Description	Personnel Required, man-yr/yr
Operators	18
Maintenance	9
Radiation monitors	5

Supplies and Utilities. Table 5.7.76 shows supplies used in DCFS operations. The utility requirements for facility operation are shown in Table 5.7.77.

TABLE 5.7.76. Supply Requirements for the Facility for Dry Caisson Storage of Packaged Spent Fuel

Material	Annual Requirement
PWR fuel racks	900
BWR fuel racks	670

TABLE 5.7.77. Dry Caisson Storage of Packaged Spent Fuel Facility Utility Requirements

Utility	Use Rate	Annual Requirements
Electricity	600 kW	5.3×10^6 kWh
Diesel oil	0.33 m^3/day	120 m^3

Hazardous Materials. No hazardous chemicals or materials other than the spent fuel are involved in normal operation of the dry caisson storage facility. Occasionally decontaminating agents, such as nitric acid or organics, may be used.

5.7.7.6 Secondary Radioactive Wastes for the Facility for Dry Caisson Storage of Packaged Spent Fuel

During normal operation little secondary radioactive wastes are generated. Decontamination of equipment or facilities would be needed when they are contaminated by small amounts of residual contamination on spent fuel package surfaces received at the DCSF. A filled package failure may occur which requires decontamination operations, but this event is not very probable. Estimated quantities of secondary waste generation are shown in Table 5.7.78.

5.7.7.7 Emissions from the Facility for Dry Caisson Storage of Packaged Spent Fuel

Estimated emissions from the reference facility operation are described in Table 5.7.79. Radionuclide releases are assumed to be negligible since the low release rates occurring during storage of unpackaged fuel (Section 5.7.1) would be further reduced by at least several orders of magnitude by containment of the fuel elements in high integrity packages.

TABLE 5.7.78. Dry Caisson Storage of Packaged Spent Fuel Facility Secondary Waste

Description	Volume, m^3/yr	Radioactivity Factors[a] Activation Products	Fission Products	Actinides
Combustible and compactable waste	170	All 1×10^{-9}	All 1×10^{-11}	0
Wet wastes	5	All 1×10^{-7}	Cs 4×10^{-8} All others 1×10^{-9}	0
Failed equipment and noncombustible waste	10	All 1×10^{-10}	All 1×10^{-12}	0

a. Fraction of input activity in secondary wastes. For input use column 3 of Table 5.7.2 and 2000 MTHM/yr.

TABLE 5.7.79. Emissions from the Facility for Dry Caisson Storage of Packaged Spent Fuel

Emissions	Description	Annual Quantity	Radioactivity Release to Atmosphere
Gaseous	Facility air	5.0×10^8 m^3/yr	Negligible
	Minor accident integrated annual release		None identified
Other	Heat	$\leq 2.0 \times 10^5$ MW-hr (6.6×10^{11} BTU)	

5.7.7.8 Decommissioning Considerations for the Facility for Dry Caisson Storage of Packaged Spent Fuel

At the end of the reference facility's operating life, the handling and storage facilities with their associated equipment are expected to be contaminated with <1 Ci of mixed fission products. Decontaminating and decommissioning plans for the facility must include appropriate decontamination systems and equipment and include monitoring and recording equipment to assess contamination levels. A quality assurance program is used during facility design and operation. Ease of material retirement and removal are an important consideration in selecting all facility materials and equipment. Any structure surfaces that are highly susceptible to hard-to-remove radionuclide contamination are covered with removable surfaces. The DCSF is designed and constructed so that it will have a useful operational life of 100 years.

5.7.7.9 Postulated Accidents for the Facility for Dry Caisson Storage of Packaged Spent Fuel

The design and operational goal of the dry caisson storage facility is the safe storage of spent fuel elements. The spent fuel storage area is a passive system; the safe storage of the spent fuel does not depend on any mechanical equipment operation. The fuel transport systems

and equipment are susceptible to mechanical failure or power loss, but these occurrences do not directly affect the safety and integrity of the fuel. Redundancy and reliability designed into all systems provide for efficient operation and additional safety. The DCFS structure is designed to withstand design basis natural disasters.

Postulated minor and moderate accident scenarios are presented in Tables 5.7.80 and 5.7.81. No accidents that could be classified as severe accidents could be realistically postulated for this technology.

TABLE 5.7.80. Dry Caisson Storage of Packaged Spent Fuel Minor Accidents

Accident Number and Description	Sequence of Events	Safety System	Release
5.7.34 — Flooding of one caisson.	1. Runoff diversion equipment fails, allowing caisson to fill with water. 2. Decay heat warms water to boiling point. 3. Water vaporizes and exits through entry point.	1. Runoff diversion system. 2. Subcritical array when flooded. 3. Canister protects fuel.	None
5.7.35 — Dropping filled fuel rack in transfer tunnel or caisson.	1. Rack grapple, grapple lifting cable, or cable winch fails when filled fuel rack is over caisson or being placed in transfer cask. 2. Filled rack falls to bottom of caisson or transfer tunnel.	1. Overpack and rack designed to withstand such a fall without loss of integrity.	None

5.7.7.10 Costs for the Facility for Dry Caisson Storage of Packaged Spent Fuel

Capital, operating, and levelized unit costs have been estimated based on mid 1976 dollars. The bases, assumptions, and definitions used in the cost estimate are described in Section 3.8.

Capital Costs. Because the DCSF is built in yearly increments, the cost estimate is presented for two phases. Table 5.7.82 shows the capital cost for Phase I, which includes construction of storage facilities for the first 2000 MTHM. The costs for this phase include:

- the fuel transfer facility, with all utilities required for the facility lifetime; the fuel transfer tunnel with its equipment, including the fuel transfer cart, television viewing system, and control system; and all other equipment and facilities located inside the FTF building.
- the finished paving, grading, and drainage work for the first year storage area including the storage area rock surface and storage caissons.
- a security fence, patrol road, and main access road necessary for the first year operations.

TABLE 5.7.81. Dry Caisson Storage of Packaged Spent Fuel Moderate Accidents

Accident Number and Description	Sequence of Events	Safety System	Release
5.7.36 — Packaged assembly fails in storage; expected frequency 5×10^{-5}/MTHM-yr of storage.	1. Canister containing a PWR assembly fails in storage due to corrosion and one PWR rod has a pinhole leak. 2. Gases are released from the caisson. 3. Leaking package detected and removed to packaging facility. 4. Overpacked package returned to caisson.	1. Caisson designed to minimize corrosion 2. Alpha activity is contained by the caisson lid. 3. Leak detection system is installed. Periodic tests are made. 4. Special handling procedures are used for failed canisters to minimize releases.	Releases at ground level are as follows: $^{3}H = 5.6 \times 10^{-3}$ Ci $^{14}C = 4.1 \times 10^{-5}$ Ci $^{85}Kr = 3.5$ Ci $^{129}I = 5.9 \times 10^{-6}$ Ci All others = negligible Assume a release period of 1 hr.

TABLE 5.7.82. Dry Caisson Storage of Packaged Spent Fuel Capital Cost Estimate, Phase I - Initial Construction for 2000 MTHM Storage

	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment			1,700		1,700
Buildings and structures		90	600	1,200	1,800
Bulk materials		20	300	200	500
Site Improvements		530	7,600	6,900	14,500
Subtotal of direct site construction costs		640	10,200	8,300	18,500
Indirect site construction costs	170	130	3,100	4,000	7,100
Total field cost	170	770	13,300	12,300	25,600
Architect-engineer services					5,100
Subtotal					30,700
Owner's cost					9,300
Total facility cost					40,000
Estimate accuracy range					±25%

Note: The costs for PWR and BWR canisters and fuel racks (all are fabricated from carbon steel) are not included in the facility cost estimates. The estimated unit costs for these items are:

	PWR	BWR
Fuel racks	$1500	$2800

Costs are based on procurement in lots of 100 or more.

- a rough grading of the entire site including future storage areas.
- equipment (cranes and casks) required for the entire period of operations.

The estimate covers all capital costs that result from making the DCSF an integral part of the associated facility (a spent fuel packaging facility or a packaged spent fuel receiving facility).

The costs also include allowances for incremental capacity additions to the associated facility for utilities such as electricity and water supplied to the DCSF and for increments in personnel facilities, change rooms, lunch rooms, etc. No allocation of general costs is made to the DCSF for laboratories, warehouse, administration office, and maintenance shops.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation except for working capital.

Table 5.7.83 gives the capital costs for Phases II through X. Each phase adds one additional 2000 MTHM storage area to the facility. Capital costs include:

- finished grading and drainage work for a 1-yr storage area, including the storage area rock surface and caissons
- average yearly costs for relocation of the security fence and patrol road, and extension of the main access roads.

TABLE 5.7.83. Dry Caisson Storage of Packaged Fuel Annual Capital Cost Estimate, Phase II: Addition of One 2000-MTHM Storage Area

	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment					
Buildings and structures					
Bulk materials					
Site improvements		440	7,500	5,700	13,200
Subtotal of direct site construction costs		440	7,500	5,700	13,200
Indirect site construction costs	120	90	2,100	2,700	4,800
Total field cost	120	530	9,600	8,400	18,000
Architect-engineer services					3,600
Subtotal					21,600
Owner's cost					6,400
Total facility cost					$28,000
Estimate accuracy range					±25%

Note: Each phase's capital cost provides an additional 2000 MTHM increment of storage capacity. Phases III through X are identical to Phase II.

Operating Cost. Operating cost components for annual facility operation are shown in Table 5.7.84. Direct labor costs are based on manpower estimates given in Table 5.7.75. Process material costs are for 897 PWR storage racks costing $1,500 each and 668 BWR racks costing $2,800 each. Costs of the carbon steel canisters are not included as operating costs because these costs are included in the packaging facility cost estimate. Utility costs are derived from requirements shown in Table 5.7.77. Annual maintenance materials costs are estimated at 3% of initial major equipment costs. Overhead and miscellaneous costs are estimated using the standard method described in Section 3.8.

The estimates for the miscellaneous items are intended to include all unidentified operating costs.

TABLE 5.7.84. Dry Caisson Storage of Packaged Spent Fuel Operating Cost Estimate

Cost Element	Annual Costs, $1000s	
Direct labor	500	
Process materials	3200	
Utilities	100	
Maintenance materials	50	
Overhead	600	
Miscellaneous	100	
Total	4550	±25%

Levelized Unit Costs. Table 5.7.85 lists the total levelized unit cost as well as the levelized capital and operating components. The cost calculations assume Federal ownership. The operating scenario is identical to the one discussed under levelized costs for packaged spent fuel water basin storage (Section 5.7.5). The effect of using round carbon steel canisters instead of rectangular canisters is discussed with the packaging facility costs, Section 5.7.3.10.

TABLE 5.7.85. Dry Caisson Storage of Packaged Spent Fuel Levelized Unit Cost Estimate

Cost Element	Unit Cost, $/kg HM	
Levelized capital charge	16.00	
Levelized operating charge	3.00	
Total levelized unit cost	19.00	±25%

5.7.7.11 Construction Requirements for the Facility for Dry Caisson Storage of Packaged Spent Fuel

Many factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The following information provides a basis for evaluating this impact.

Project Schedules and Construction Manpower. The initial phase construction of the DCSF occurs at the same time as the construction of the adjacent reference facility (see Section 5.7.3.11). The estimated field labor force for DCSF construction is listed below:

	Man-hours, 1000s	
	Phase I	Each Phase II-X
Manual field labor	770	530
Nonmanual field labor	170	120
Total field labor	940	650

These construction manhours are integrated with labor schedules for the associated reference facility.

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the DCSF. Offsite costs include all services, equipment fabrication and assembly, and materials purchased elsewhere. The distribution of total costs in these categories is shown below:

	Costs, $1000s	
	Phase I	Each Phase II-X
Onsite	14,000	10,000
Offsite	26,000	18,000
Total	40,000	28,000

Site Requirements. Land commitments for the DCSF are included with those for the associated reference facility. The DCSF requires additional access roads and parking areas. Approximately 129 ha (320 acres) of additional plant area is required at the associated reference facility plus an area of 2 ha (5 acres) adjacent to the DCSF for construction storage work yards, temporary buildings, and labor parking.

Water. Approximately 15,000 m^3 (4 x 10^6 gal) of water are used during the initial (Phase I) construction. For each construction increment (Phases II-X), 10,000 m^3 (2.7 x 10^6 gal) are used.

Construction Materials. Materials committed to the construction of the facility are:

	Phase I		Each Phase II-X	
Concrete	16,000 m^3	(21,000 yd^3)	14,000 m^3	(18,000 yd^3)
Steel	3,200 MT	(3,500 tons)	2,600 MT	(2,900 tons)
Lead	63 MT	(70 tons)	-	-
Lumber	94 m^3	(40 MFBM)	12 m^3	(5 MFBM)

Energy. Energy resources used during construction are:

	Phase I		Each Phase II-X	
Propane	114 m^3	(30,000 gal)	76 m^3	(20,000 gal)
Diesel fuel	1140 m^3	(300,000 gal)	760 m^3	(200,000 gal)
Gasoline	760 m^3	(200,000 gal)	490 m^3	(130,000 gal)
Electricity				
Peak demand	300 kW		200 kW	
Total consumption	550,000 kWh		370,000 kWh	

Transportation Requirements. No transportation requirements for the DCSF have been identified other than those for the associated facility.

5.7.7.12 Effects of Fuel Cycle Options

The effect of fuel cycle options would be the same as those discussed in 5.7.5.12.

5.7.8 Surface Cask Storage of Packaged Spent Fuel

The fourth alternative for extended storage of packaged spent fuel is referred to here as the surface cask concept. With the surface cask concept, packaged spent fuel is stored in a reinforced concrete radiation shield. Convective air flow through openings in the base of the shield and past the vertical spent fuel packages dissipates the heat generated by the fuel to the atmosphere. This concept has been extensively studied[17] and tested for storage of solidified high-level waste. The concept has not yet been used for storage of actual spent reactor fuels or high-level waste, but the concept is a straightforward application of existing technology. Canada is using a concept[10,21] similar to the sealed cask concept to store Canadian reactor fuels except that the heat generated by the fuel is conducted through the concrete shield instead of being removed by air convection.

5.7.8.1 Alternatives for Surface Cask Storage of Packaged Spent Fuel

The surface cask concept is relatively simple. Alternatives for this concept include design optimization to insure storage unit safety and maintainance of reasonable costs and ease of spent fuel retrievability. The reference facility design is based on the sealed storage cask concept for solidified high-level waste storage because of the similarity of storage requirements and the extensive design effort that has already been completed. Alternative areas which could be investigated include using different shielding materials, such as high density concrete or a steel and water combination, and reviewing various configurations to minimize the shielding material costs per MTHM of stored fuel.

Double containment of the spent fuel is provided by single encapsulation of unfailed fuel assemblies (cladding is one barrier and the canister is the second) and by double encapsulation (overpacking) of any failed assemblies. A more conservative approach would be to doubly encapsulate all of the assemblies.

5.7.8.2 Design Basis for the Facility for Surface Cask Storage of Packaged Spent Fuel

The following assumptions were made in the design of the reference facility:

- The surface cask storage facility (SCSF) is associated with either a spent fuel packaging facility or an independent facility for receiving packaged spent fuel. All supporting facilities and services other than those peculiar to the storage facility are provided by the associated facility.
- The storage facility receives packaged fuel assemblies at a rate up to 2000 MTHM per year (2690 PWR assemblies and 4030 BWR assemblies).
- The average exposure of the spent fuel is approximately 29,000 MWD/MTHM, and it is aged at least 6.5 years from reactor discharge.
- The number of fuel assemblies per storage unit is determined by the ability of the facility to handle shield and packaged fuel weight. For this study, the maximum weight

that can be handled is assumed to be about 123 MT (135 tons). With a 5.0 m (16.4 ft) high cavity and a shield thickness of 102 cm (40 in.), a storage cavity roughly 91 cm (36 in.) in diameter would be allowed. This cavity would accommodate four PWR assemblies or nine BWR assemblies, representing about 1.8 MTHM of fuel generating about 2.5 kW of heat.

- The initial construction module provides storage for 2000 MTHM of spent fuel or 1120 storage units. Additional modules of 1120 units will be built as required until the facility reaches reference storage capacity of 20,000 MTHM or 11,200 storage units.
- The facility is designed for 100-year storage capability, although the use period is expected to be significantly less. After interim storage the packaged fuel is retrieved for shipment to a repository or reprocessing facility.

5.7.8.3 Operation of the Facility for Surface Cask Storage of Packaged Spent Fuel

The SCSF operations include receiving the packaged spent fuel, receiving and inspecting new storage casks, inserting the racked packaged spent fuel in a storage cask unit, transporting the cask unit to the storage area, and placing it there. Figure 5.7.79 is a schematic flow diagram showing the major facility operations.

In the associated faciiity (SFPF or PFRF), packaged spent fuel assemblies are inserted into an appropriate rack (designed for PWR or BWR assemblies). The rack is moved through a transfer tunnel to the SCSF on a self-propelled cart. The rack is moved to a remotely operated cell in the SCSF where the crane positions the rack into a holding frame within the storage cask. These operations are performed with remotely operated grapples and are observed with television cameras. The storage cask is then moved through the cask transfer tunnel to a loading area where it is picked up by a crane and placed on a tractor-trailer transport for movement to its storage location. The tractor-trailer moves the filled storage cask next to its storage position where a mobile gantry crane picks up the unit and places it on a preplaced concrete pad. Both the tractor-trailer and the gantry crane return to the cask receiving area where the gantry crane places a new empty storage cask on the tractor-trailer. The tractor-trailer delivers the new storage cask unit to the SCSF and the gantry crane moves to the next cask storage location.

New storage casks, which are received from railroad cars, are unloaded, inspected, and placed in a storage area until ready for use. Shield bases are preinstalled in the storage area.

The storage area is monitored for radionuclide leakage from the storage units (leakage is not considered a very probable event). Should radionuclides escape from a storage unit, the unit is retrieved from the storage area and returned to the packaging facility for inspection and repair or replacement of the fuel packages. Retrieval procedures are the reverse of loading procedures. If radionuclide contamination of SCSF structure and equipment occurs, conventional decontamination techniques will be employed. Wastes resulting from decontamination operations are immobilized and shipped offsite for treatment and/or storage.

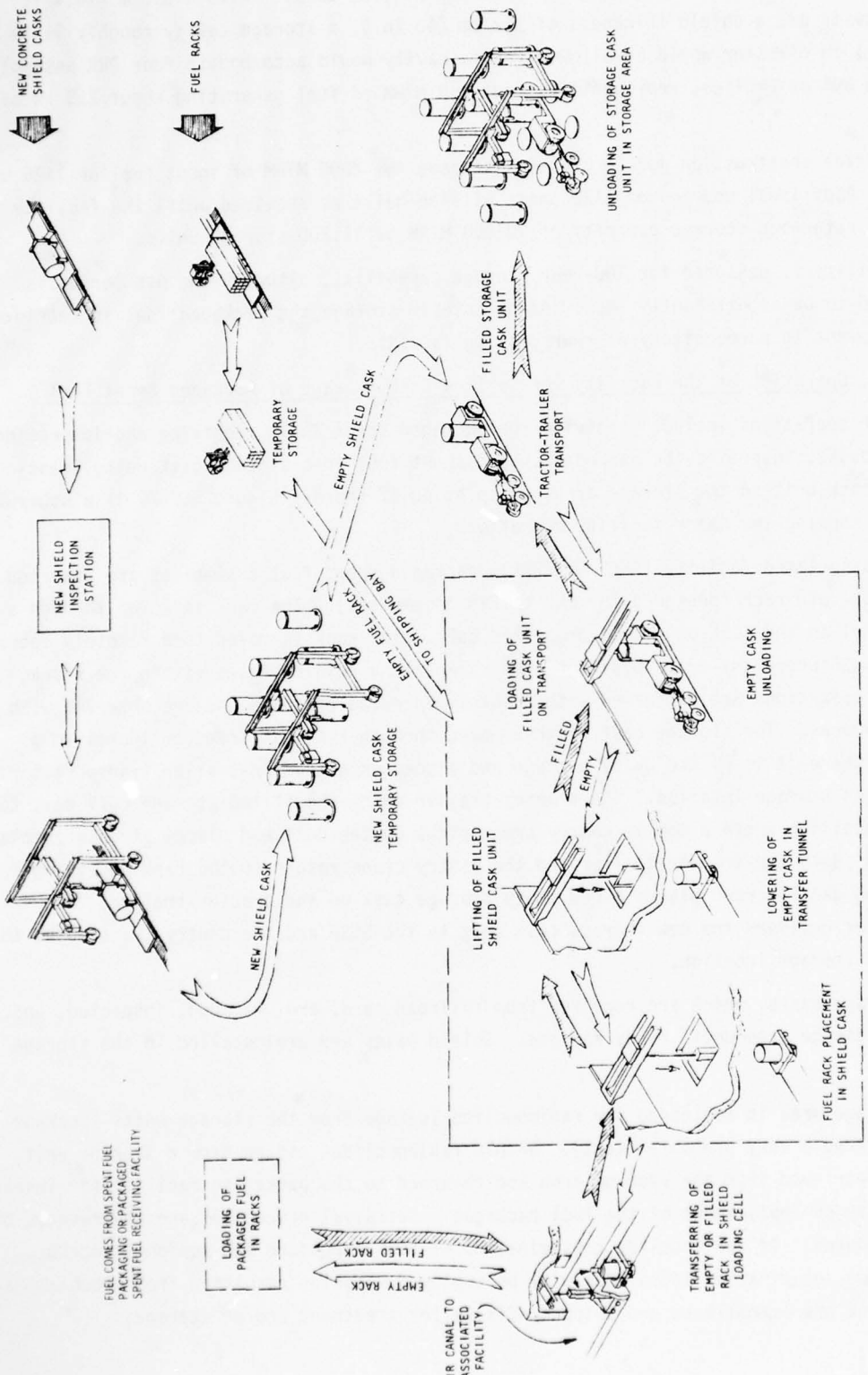


FIGURE 5.7.79. Operations Flow Diagram for the Facility for Surface Cask Storage of Packaged Spent Fuel

The storage system for the storage units is completely passive. Heat that is generated by the spent fuel is conducted and radiated to the air flow channel (annulus) between the packaged spent fuel and its shielded storage cask (see Figure 5.7.80). The heated air in the annulus induces a natural convection air flow or chimney effect with air entering the channels at the bottom of the cask shield, passing through the annulus, and exiting through the top of the shield. Labyrinth air channels in the storage cask shielding prevent radiation from streaming through the inlet or exit air ports. A filled storage facility initially generates 21.6 MW of radionuclide decay heat.

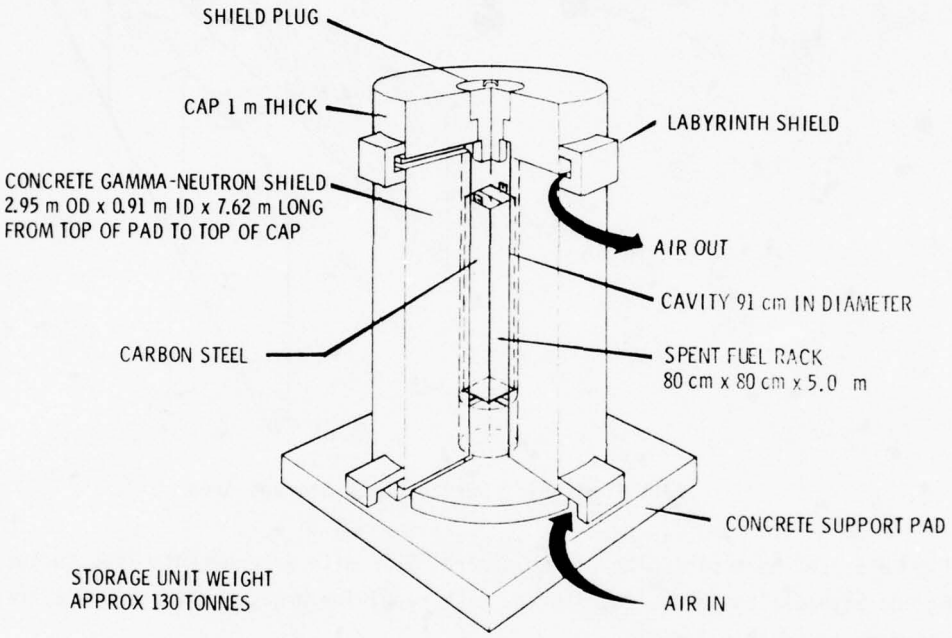


FIGURE 5.7.80. Surface Cask Storage Unit

Individual storage units can be monitored to detect radionuclide leakage. Any plugged air ports are indicated by a rise in exit air temperature. A central system automatically monitors storage area surveillance instruments. If abnormal conditions are detected, an alarm will sound and corrective action will be taken.

5.7.8.4 Description of the Facility for Surface Cask Storage of Packaged Spent Fuel

Because of the similarity between the storage of spent fuel and the storage of high-level wastes, the surface storage cask techniques which were developed for high-level waste storage in a retrievable surface storage facility[17] are used in the SCSF to store the packaged spent fuel elements. A typical storage cask unit, shown in Figure 5.7.80, consists of a fuel rack and a reinforced concrete shield. Each unit stores four PWR or nine BWR packaged spent fuel assemblies. Each storage shield unit is stored vertically on concrete pads which are arranged in a rectangular array within a double fenced, controlled area (see Figure 5.7.81).

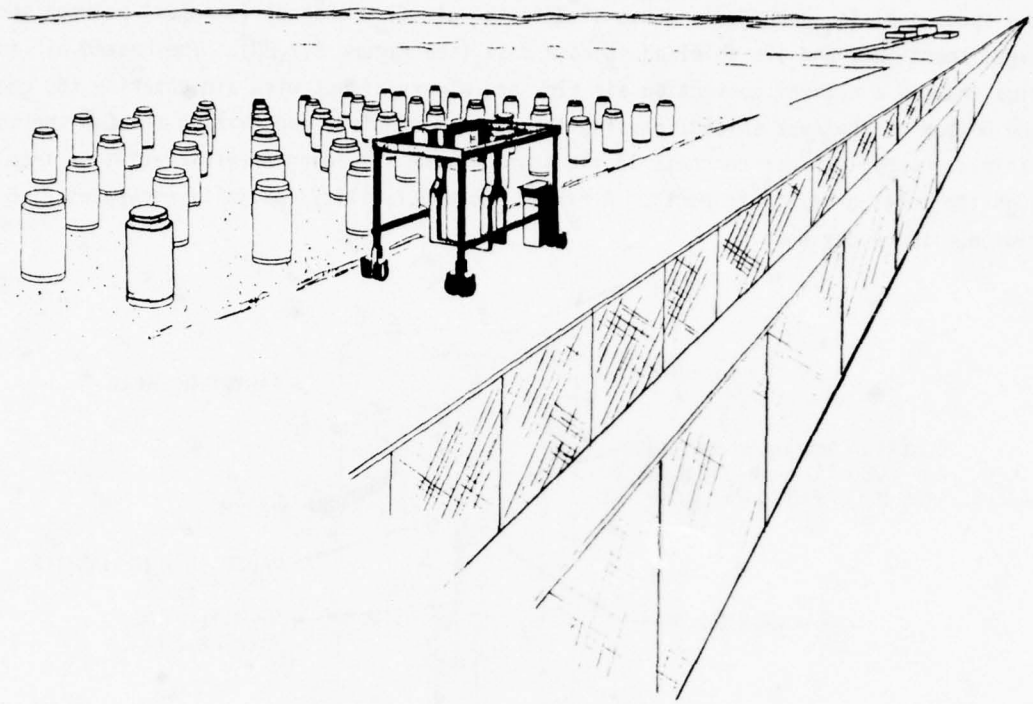


FIGURE 5.7.81. Surface Cask Storage Area

Figure 5.7.82 is a plot plan of the general SCSF site arrangement; the storage cask loading and assembly building, the storage cask receiving area, and the storage area are the major components of this facility.

Storage Cask Loading and Assembly Building. Figure 5.7.83 is an equipment and facility arrangement drawing showing the layout of the storage cask loading and assembly building. This building covers approximately 743 m^2 (8000 ft^2) and houses the storage cask loading cell, the cask transfer tunnel, the operating/control room, and the shipping bay. All functional areas are within a reinforced concrete structure. The storage casks are moved from the loading cell to the shipping bay through the transfer tunnel, which has a depth of about 8.8 m (29 ft) below ground level.

The shipping bay is a steel framed high bay area with insulated metal siding. The bay accommodates temporary storage of the filled storage cask awaiting placement in the storage area and also storage cask handling equipment including a 150 ton bridge crane and a tractor-trailer transport.

Storage Cask Receiving Area. The storage cask receiving area (SCRA) is a paved area of about 26,000 m^2 (280,000 ft^2) shown in the lower portion of Figure 5.7.84. The area includes a rail system, a shielded cask receiving/inspection station, and interim storage for new shield

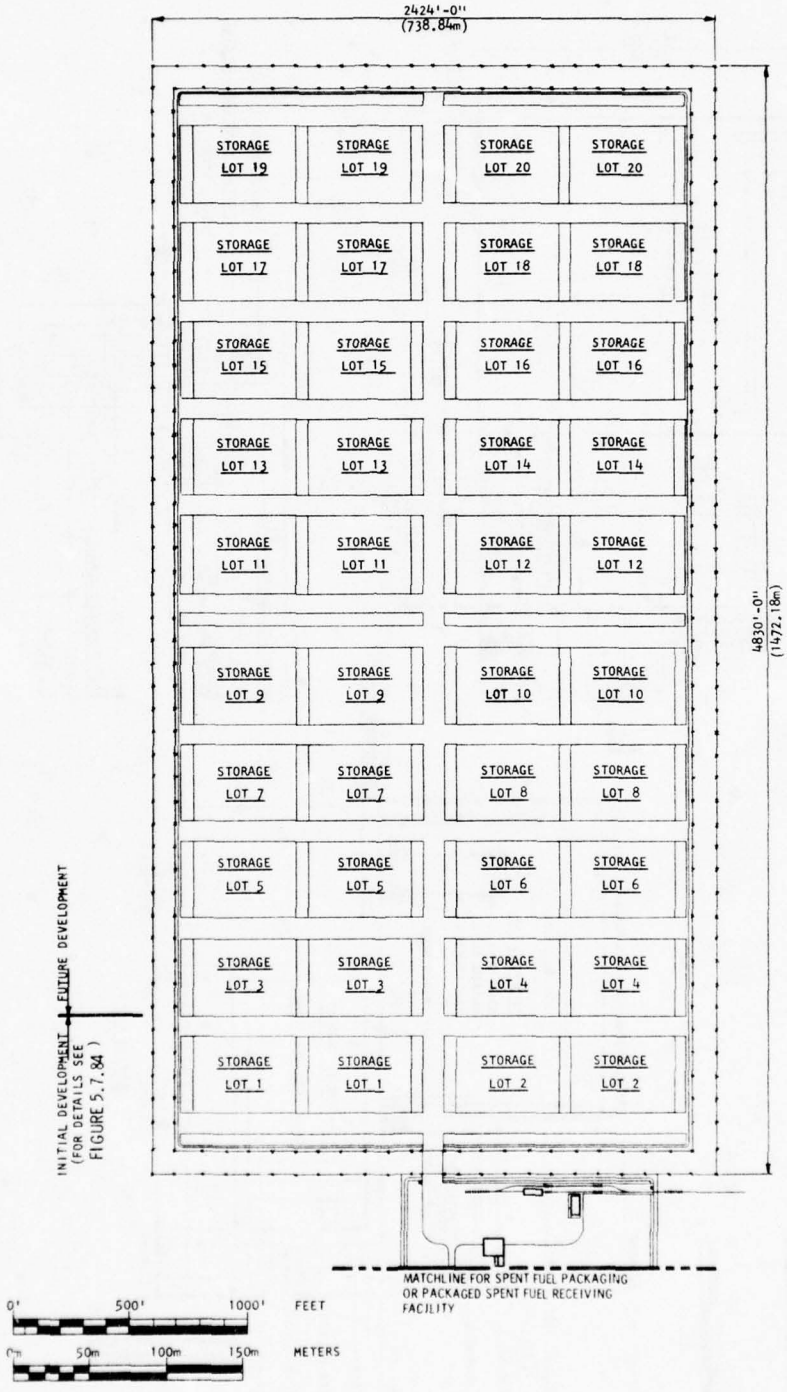


FIGURE 5.7.82. Plot Plan for the SCSF

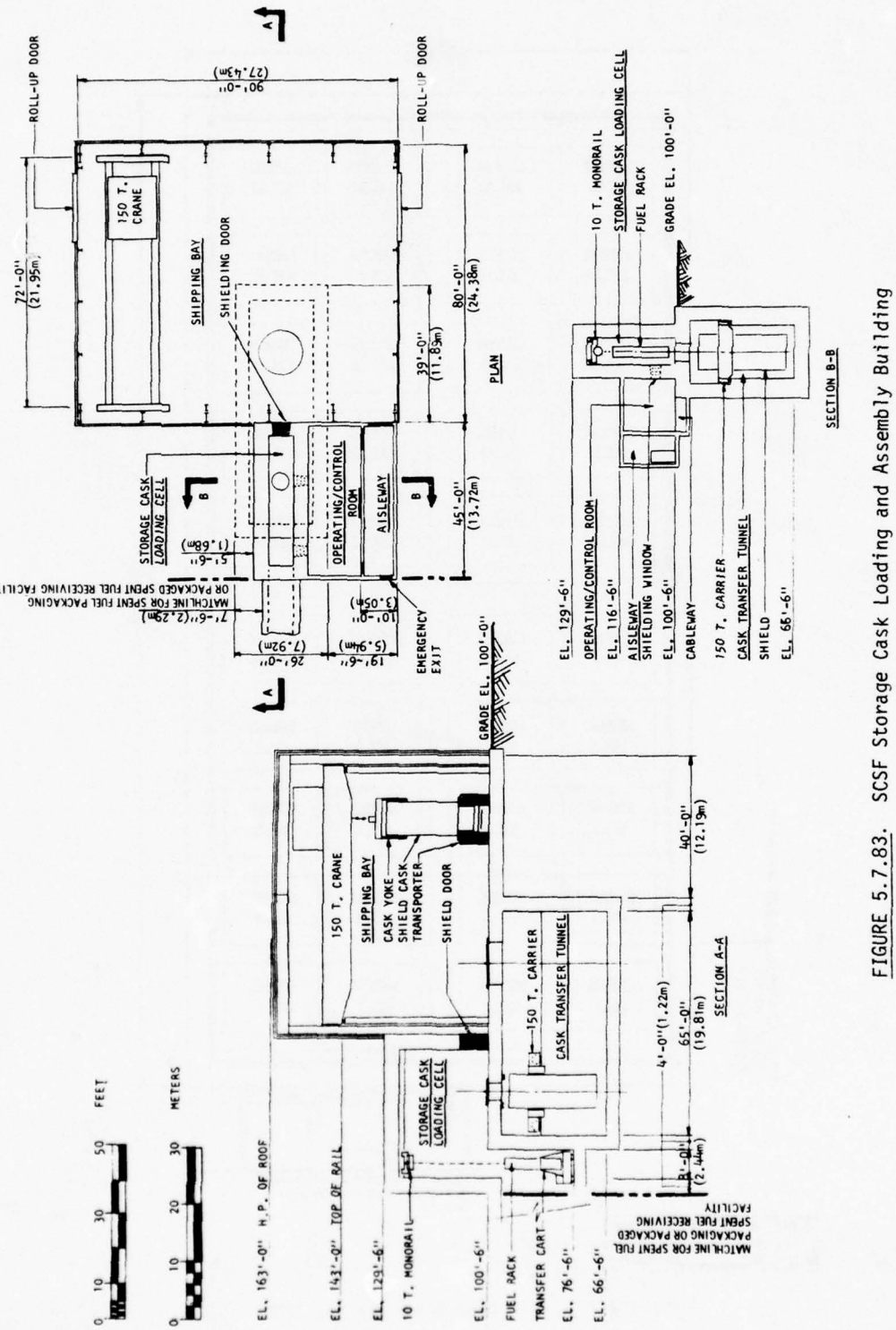


FIGURE 5.7.83. SCSF Storage Cask Loading and Assembly Building

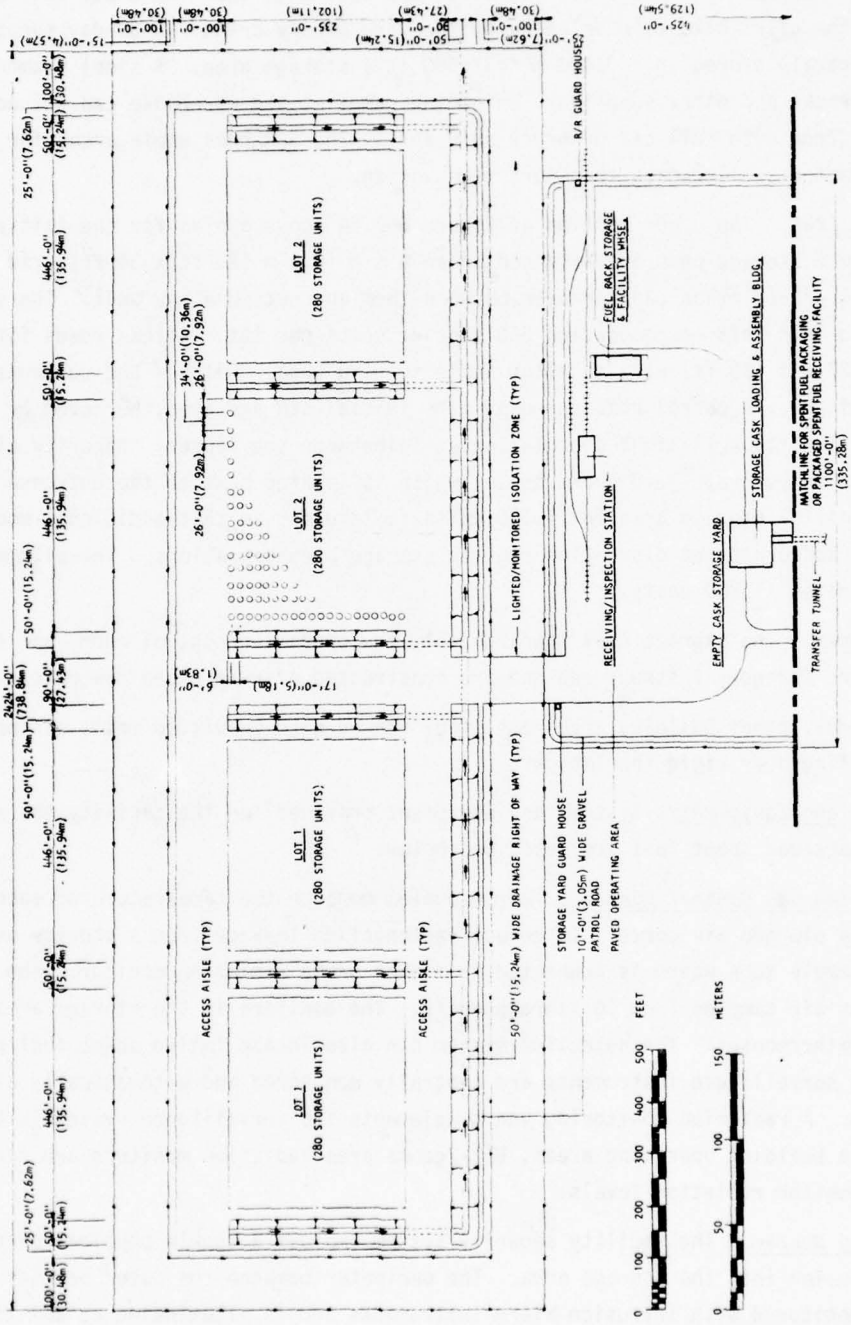


FIGURE 5.7.84. SCSF Storage Cask Receiving and Initial Phase Storage Area Plot Plan

casks and fuel rack supplies. The inspection station is a structural steel framed building opened at both ends to allow rail cars to pass through. The railroad track next to the inspection station is a second spur which rejoins the incoming (main) spur about 30 m (100 ft) inside the perimeter fence. The second spur is used as a siding so that the empty rail cars can be moved after the casks have been unloaded by the yard gantry crane. A 30-day supply of new casks can be temporarily stored in a 3,480 m^2 (37,500 ft^2) storage area. A steel framed warehouse stores fuel racks and other supplies. Unloading ramps at the warehouse can unload fuel racks and supplies from both rail car or truck shipments. The SCRA has ample areas for yard gantry crane and tractor-trailer cask transport maneuvering.

Storage Area. The upper portion of Figure 5.7.84 shows a plan for the initial storage area. Concrete storage pads are arranged on an 8 m x 10.3 m (26 ft x 34 ft) grid pattern such that the yard gantry crane can maneuver between them and retrieve any unit. The storage area is subdivided into lots accommodating 560 storage units per lot. Access roads for the tractor-trailer are 27.4 m (90 ft) wide to allow ample turning room. Ditches and culverts are arranged for area drainage. A patrol road surrounds the initial storage area, bordered by two fences with a 30 m (100 ft) well-lighted exclusion strip between the fences. Security alarm instruments are housed in the storage yard guard house, which is located next to the entrance of the storage area. The initial storage area for 1,120 units is laid out so that additional modular storage areas can be added without disrupting regular storage area operations. The ultimate storage area accommodates 11,200 units.

Structures. The storage cask loading cell, the operating/control room, and the cask transfer funnel are Category I structures and are constructed of reinforced concrete.

In general, other building areas are steel framed with insulated metal siding. Roofs are built-up roofing over rigid insulation.

Systems and Equipment. Systems and equipment provided for the facility for surface cask storage of packaged spent fuel are described below:

Monitoring and Control System. Thermocouples monitor the temperature of each storage unit to detect any plugged air ports. To detect radionuclide leakage from a storage unit, each unit has an air sample tube which is connected to a beta-gamma radiation monitor. The radiation monitor tests air samples from 10 storage units. The monitors in the storage area are protected by weatherhouses. The detection system can also locate failed spent fuel packages. Storage area surveillance instruments are centrally monitored and automatically alarmed in the control room. A radiation monitoring van supplements the surveillance system in the storage area. Within building operating areas, beta/gamma area radiation monitors are strategically located to monitor radiation levels.

Security System. The facility security system employs a double physical barrier to guard against intrusion into the storage area. The perimeter between the outer barrier and inner barrier is monitored with intrusion alarm instruments and is illuminated at all times.

Ventilation System. Outside air is drawn into the shipping bay through filters and dampers to the cask transfer tunnel. From there, the air passes through exhaust ports in the tunnel and through HEPA filters and is released into the atmosphere by a blower. Space heaters maintain a winter temperature in the shipping bay above 16°C (60°F). A separate ventilation system is provided for personnel areas (the operating/control room and the aisleway), and these areas are air conditioned, with 80% recirculation. The cask loading cell, which is connected to the associated facility, is ventilated by the parent plant ventilation system.

Material Handling Equipment. The major storage unit handling equipment items used in the surface cask storage facility are listed in Table 5.7.86.

TABLE 5.7.86. Material Handling Equipment

Item	Primary Function
Track mobile	Moves rail cars at the cask receiving area
Yard forklift	Unloads fuel racks and supplies from rail car or truck shipments
Mobile yard gantry crane	Handles storage units in the storage area and receives new shield casks at the cask receiving area
Tractor-trailer transport	Transports filled or empty storage units between the shipping bay and the storage area
150 ton capacity bridge crane with auxiliary hoist	Handles storage cask units and inserts empty fuel racks into the shield cask at the shipping bay
Storage unit carriage	Moves the storage unit through the transfer tunnel from the cask loading cell to the shipping bay
10 ton twin-beam monorail crane with remotely operated grapple	Removes the shield plug from the cask cover and handles fuel racks in the storage cask loading cell
Fuel rack transfer cart	Transports fuel racks between the SCSF and the associated facility
Master-slave manipulator	This is not normally installed at the storage cask loading cell. However, the cell walls have penetration sleeves for master-slave manipulators if the crane or grapple should malfunction while a filled rack is being handled.
Remotely-operated control and television monitors	Enables operators to visually observe remote operations in the air canal between SCSF and the associated facility, the storage cask loading cell, and the cask transfer tunnel.

5.7.8.5 Operating and Maintenance Requirements for the Facility for Surface Cask Storage of Spent Packaged Fuel

The reference facility is designed to operate 24 hours a day, 7 days a week. It is estimated that it takes the tractor-trailer 4 hr to make a round trip to place a filled storage unit in the storage area, therefore, three shifts per day would be required to move the filled units with 1 tractor-trailer. Only two shifts per day are needed to load the racked spent fuel packages into the shields. The filled shields (storage casks) can be left temporarily in the loading and assembly building or in an adjacent temporary storage area to await

placement in the storage area. Normal facility activities include insertion of packaged spent fuel in racks then in shield assemblies (storage units), storage unit placement and removal, storage area monitoring, and maintenance activities.

Operations and Maintenance. Remote operations include placing packaged fuel in racks, assembling the shield, and placing the shield on the storage unit base. These operations are performed remotely because of the radiation dose from the shield assembly before the storage unit is installed on its base. All other operating and maintenance activities are performed manually. Because spent fuel package surfaces are protected and decontaminated, no signfi-cant residual contamination problems are expected.

Radiation dose rates through the shield walls are limited to $\leq$1 mrem/hr, but the radiation streaming through the shield air ports may be as high as 10 mrem/hr. The dose rate in the storage area is limited to $\leq$10 mrem/hr. However, the storage area is not a normal work area for operating personnel, whose exposure is limited to an average of $\leq$ 1 mrem/hr. Dose rates for access roads into the storage arrays are limited to a 10 mrem/yr. Some maintenance require-ments may cause the dose rate to exceed this, but the doses will be controlled to well within the limits of Title 10, Part 20 of the Code of Federal Regulations.[8]

The storage cask loading and assembly building is maintained with contact techniques. The storage area is essentially maintenance free. Only periodic surface ground keeping maintenance is necessary. If a fuel package fails (very unusual) and requires the removal of the filled shield assembly, the cask loading cell can perform these services remotely.

Staffing. Estimated staffing requirements for the facility are shown in Table 5.7.87.

TABLE 5.7.87. Staffing Requirements for Surface Cask Storage of Packaged Spent Fuel

Job Description	Personnel Required, man-yr/yr
Operators	34
Maintenance	16
Radiation monitors	10

Supplies and Utilities. Table 5.7.88 shows the supplies used in SCSF operations. Table 5.7.89 lists the utilities required to operate the SCSF.

TABLE 5.7.88. Supply Requirements for Surface Cask Storage of Packaged Spent Fuel

Material	Use	Annual Requirement
Racks	Hold filled	
PWR	canisters	680
BWR		450
Radiation shields (casks)	Hold filled	
PWR	racks	680
BWR		450

TABLE 5.7.89. Surface Cask Storage of Packaged Spent Fuel Facility Utility Requirements

Utility	Use Rate	Annual Requirement
Electricity	600 kW	5.3×10^6 kWh
Gasoline	0.16 m^3/day	58 m^3

Hazardous Materials. Except for the packaged spent fuel, the only hazardous materials present in SCSF operations are decontamination agents, such as nitric acid and some organics, which are used according to safe industrial practice.

5.7.8.6 Secondary Radioactive Wastes for the Facility for Surface Cask Storage of Packaged Spent Fuel

Secondary radioactive wastes released from the reference facility are shown in Table 5.7.90.

TABLE 5.7.90. Secondary Wastes for the Facility for Surface Cask Storage of Packaged Spent Fuel

Description	Volume, m^3/yr	Radioactivity Factors[a]		
		Activation Products	Fission Products	Actinides
Combustible and compactable waste	170	All 1×10^{-9}	All 1×10^{-11}	0
Wet wastes	5	All 1×10^{-7}	Cs 4×10^{-8} All others 1×10^{-9}	0
Failed equipment and noncombustible waste	10	All 1×10^{-10}	All 1×10^{-12}	0

a. Fraction of input activity in secondary wastes. For input use column 3 of Table 5.7.2 and 2000 MTHM/yr.

5.7.8.7 Emissions from the Facility for Surface Cask Storage of Packaged Spent Fuel

Estimated emissions from the reference facility operation are described in Table 5.7.91. Radionuclide releases are assumed to be negligible since the low release rates occurring during storage of unpackaged fuel (Section 5.7.1) would be further reduced by at least several orders of magnitude by containment of the fuel elements in high integrity packages.

5.7.8.8 Decommissioning Considerations for the Facility for Surface Cask Storage of Packaged Spent Fuel

At the end of the reference facility's operating life, handling and storage facilities with their associated equipment are expected to be contaminated with <1 Ci of mixed fission products. Design plans for decontaminating and decommissioning the facility provide for appropriate decontamination equipment and systems and for monitoring and recording equipment needed

TABLE 5.7.91. Emissions from the Facility for Surface Cask Storage of Packaged Spent Fuel

Emissions	Description	Annual Quantity	Radioactivity Release to Atmosphere
Gaseous	Facility air	5×10^8 m^3	Negligible
	Minor accident integrated annual release		None identified
Other	Heat	$\leq 2.0 \times 10^5$ MW-hr (6.6×10^{11} BTU)	

to assess contamination levels. Ease of retirement and removal is an important consideration in selecting materials and equipment for the facility. Any facility structure surfaces that are highly susceptible to hard-to-remove radionuclide contamination are covered with removable surfaces. A quality assurance program is initiated during plant design and continued during plant operation. The SCSF is designed and constructed so that it has a useful operating life of 100 years.

5.7.8.9 Postulated Accidents for Surface Cask Storage of Packaged Spent Fuel

Safe storage of packaged spent fuel is the design and operational goal of the SCSF. The facility has highly reliable passive cooling, atmospheric protection, and containment systems.

Postulated minor and moderate accident scenarios for the reference SCSF are given in Tables 5.7.92 and 5.7.93. Accidents which have been postulated during filled rack transfer and storage shield assembly operations are of equal or lesser extent than would occur in the spent fuel packaging facility. Other potential accidents are similar to those using the same concept for storage of solidified HLLW and are analyzed in Section 5.4.2 and in Retrievable Surface Storage Facility Conceptual System Design Description.[17]

For purposes of environmental consequence analysis, the material release associated with accident number 5.7.39 in Table 5.7.93 has been selected as an umbrella source term. (The concept of an umbrella source term is explained in Section 3.7.) This means that the release from this accident is the largest in its respective source term category. The environmental consequences of this accident are described in DOE/ET-0029.

Accidents are cross-indexed with their appropriate umbrella source terms in Appendix A, Section 3.

5.7.8.10 Costs for the Facility for Surface Cask Storage of Packaged Spent Fuel Storage

Estimates have been made in mid-year 1976 dollars for capital, operating, and levelized unit costs. A complete description of the cost estimate bases, assumptions, and definitions is given in Section 3.8.

TABLE 5.7.92. Minor Accidents Postulated for Sealed Cask Storage of Packaged Spent Fuel

Accident Number and Description	Sequence of Events	Safety Systems	Release
5.7.37-Loss of cooling air flow.	1. Debris plugs air intake to storage unit. 2. Fuel self heats and sets off high temperature alarm. 3. Blockage removed after temperature alarm indicates blockage. 4. Fuel returns to normal temperature.	1. System designed to minimize plugging. 2. Units designed to maintain fuel temperature below a value that ensures containment integrity during a complete air flow blockage. 3. Remote temperature monitoring and alarms for each storage unit.	None
5.7.38-Filled fuel rack dropped in transfer tunnel or storage cask.	1. Rack grapple, grapple lifting cable, or cable winch fails when filled fuel rack is over storage cask or being placed in transfer tunnel. 2. Filled rack falls to bottom of storage cask or transfer tunnel.	1. Overpack and rack designed to withstand such a fall without loss of integrity.	None

TABLE 5.7.93. Moderate Accidents Postulated for Sealed Cask Storage of Packaged Spent Fuel

Accident Number and Description	Sequence of Events	Safety Systems	Release
5.7.39-Packaged assembly fails in storage; expected frequency 5 x 10^{-5}/ MTHM-yr of storage.	1. Canister containing one PWR assembly fails in storage due to corrosion. One PWR rod has a pin hole leak. 2. Gases are released. 3. Leaking package detected and removed to packaging facility. 4. Overpacked package returned to surface cask.	1. Surface cask designed to minimize corrosion. 2. Leak detection system is installed. Periodic tests are made. 3. Special handling procedures are used for failed canisters to minimize releases.	Releases over a 15 min. period at ground level as follows: ^{3}H = 5.6 x 10^{-3} Ci ^{14}C = 4.1 x 10^{-5} Ci ^{85}Kr = 3.5 Ci ^{129}I = 5.9 x 10^{-6} Ci All others = negligible

Capital Costs. The capital cost estimate for SCSF initial phase is shown in Table 5.7.94. The estimate covers all capital costs specifically resulting from addition of an operational SCSF to either a spent fuel packaging facility or an independent packaged fuel receiving facility. These capital costs cover the engineering, supply and construction of the initial phase of an SCSF so that it is operational.

The initial construction phase consists of:

- All receiving, assembly, administration, security, and support facilities shown in Figures 5.7.83 and 5.7.84.

TABLE 5.7.94. Capital Cost Estimate for Surface Cask Storage of Packaged Spent Fuel, Initial Construction Phase

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		10	2,400	100	2,500
Buildings and structures		180	1,200	2,300	3,500
Bulk materials		380	2,100	5,000	7,100
Site improvements		240	800	3,000	3,800
Subtotal of direct site construction costs		810	6,500	10,400	16,900
Indirect site construction costs	210	160	3,800	5,000	8,800
Total field cost	210	970	10,300	15,400	25,700
Architect-engineer services					5,100
Subtotal					30,800
Owner's cost					9,200
Total facility costs					40,000
Estimate accuracy range					±25%

Note: Components for 500 storage units, consisting of concrete shields and carbon steel fuel racks, are estimated to cost an additional $8,000,000 (total direct cost).

- An initial storage area for 1120 storage units (Lots #1 and #2 on the plot plan, Figure 5.7.84)
- Rough grading for the remainder of the storage area (Lots #3 through #20).

The cost of an initial inventory of fabricated parts for the first 500 storage units is reported separately as a note to Table 5.7.94. This cost is not included in the total facility cost.

The site is intended for modular future expansion. Table 5.7.95 gives the estimated cost to add one 1120 unit storage area module. Modules are added yearly until reference facility size is reached (11,200 units).

The SCSF cost estimates also include the incremental additions to the associated facility for the utilities supplied to the SCSF. No allocation of general costs is made to the SCSF for support services such as laboratories, administration office, maintenance shops, etc.

TABLE 5.7.95. Capital Cost Estimate for Surface Cask Storage of Packaged Spent Fuel, Annual Incremental Cost to Add One 1120-Unit Storage Area

Cost Element	Man-hours, 1000s		Costs, 1000s of Mid-1976 Dollars		
	Nonmanual	Manual	Material	Labor	Total
Major equipment		-	--	--	--
Buildings and structures		-	--	--	--
Bulk materials		360	2,000	4,600	6,600
Site improvements		70	200	1,000	1,200
Subtotal of direct site construction costs		430	2,200	5,600	7,800
Indirect site construction costs	110	90	2,100	2,900	5,000
Total field cost	110	520	4,300	8,500	12,800
Architect-engineer services					2,600
Subtotal					15,400
Owner's cost					4,600
Total facility cost					20,000
Estimated accuracy range					±25%

Note: The unit cost for storage cask foundation pads is not included above. The unit total field cost for these pads in quantities of one to two hundred units is estimated to be $4,000 each.

The total capital cost includes all plant-related costs incurred from the start of engineering to the initiation of commercial operation except for working capital. Costs of storage unit components are included in operating costs.

Operating Costs. The operating cost components for annual operation of the facility, when receiving and storing fuel at the rate of 2000 MT/yr, are shown in Table 5.7.96. Direct labor costs are based on manpower estimates given in Table 5.7.87. Process material costs include the costs of carbon steel fuel racks, concrete radiation shields and concrete pads for the storage units. The 1120 storage units cost about $20,000 each. Utility costs are derived from requirements shown in Table 5.7.89. Annual maintenance materials costs are estimated at 3% of initial major equipment costs. Overhead and miscellaneous costs are estimated using the standard method described in Section 3.8. The estimates for the miscellaneous items are intended to include all unidentified operating costs.

Levelized Unit Cost. Table 5.7.97 lists the total levelized unit cost as well as the capital and operating components. Cost calculations assume Federal ownership of the facility. The operating scenario is the same as that discussed under levelized costs for packaged spent fuel water basin storage (Section 5.7.5). The effect of using round carbon steel canisters instead of rectangular canisters is discussed with the packaging facility costs, Section 5.7.3.10.

TABLE 5.7.96. Operating Cost Estimate for Surface Cask Storage of Packaged Spent Fuel

Cost Element	Annual Costs, $1000s	
Direct Labor	600	
Process materials	22,400	
Utilities	100	
Maintenance materials	75	
Overhead	725	
Miscellaneous	100	
Total	24,000	±25%

TABLE 5.7.97. Surface Cask Storage of Packaged Spent Fuel Facility Levelized Unit Cost Estimate

Cost Element	Unit Cost $/kg HM	
Levelized capital charge	13.00	
Levelized operating charge	12.80	
Levelized total unit cost	25.80	±20%

5.7.8.11 Construction Requirements for Surface Cask Storage of Packaged Spent Fuel Facility

Many of the factors relating to site preparation and reference facility construction may have some impact on the environment, the local economy, and the natural resources of the surrounding area. The following information provides a basis for evaluating this impact.

Project Schedules and Construction Manpower. Engineering, procurement, and construction schedules, as well as the field labor force estimate for the SCSF initial construction phase, are integrated with the schedules and estimates for the associated facility described in Section 5.7.3.11. The field labor force estimates for the initial construction phase and for each yearly addition to the SCSF is shown below:

	Initial Phase Man-hours, 1000s	Yearly Additional Man-hours, 1000s
Manual field labor	970	520
Nonmanual field labor	210	110
Total field labor	1180	630

Distribution of Onsite and Offsite Costs. Onsite costs are those for all construction, materials, and services provided at the site of the associated facility. Offsite costs are those for services, equipment fabrication and assembly, and materials purchased elsewhere. The distribution of total costs in these categories is shown below:

	Initial Phase Costs, $1000s	Yearly Additional Costs, $1000s
Onsite	17,000	9,000
Offsite	23,000	11,000
Total	40,000	20,000

Site Requirements. Land commitments for the SCSF are included with those of the associated facility. Within the associated facility site, approximately 108 ha (268 acres) are required for the SCSF storage areas.

Water. Water used during the initial construction period is approximately 1.4×10^4 m^3 (3.8×10^6 gal). Thereafter, the annual additional requirements are 7.5×10^3 m^3 (2.0×10^6 gal).

Construction Materials. Materials committed to the reference facility are:

	Initial Phase Construction	Yearly Additions
Concrete	4,700 m^3 (6,200 yd^3)	380 m^3 (500 yd^3)
Steel	1,200 MT (1,300 tons)	180 MT (200 tons)
Copper	4.5 MT (5 tons)	4.5 MT (5 tons)
Lumber	200 m^3 (85 MFBM)	12 m^3 (5 MFBM)

Energy. Energy resources used during construction of the reference facility are:

Propane	130 m^3 (35,000 gal)	76 m^3 (20,000 gal)
Diesel fuel	1,330 m^3 (350,000 gal)	720 m^3 (190,000 gal)
Gasoline	870 m^3 (230,000 gal)	490 m^3 (130,000 gal)
Electricity		
Peak demand	350 kW	570 kW
Total consumption	675,000 kWh	360,000 kWh

Transportation Requirements. No transportation requirements for the surface cask storage facility have been identified other than those for the associated facility.

5.7.8.12 Effects of Fuel Cycle Options

The effect of fuel cycle options would be the same as those discussed in Section 5.7.5.12.

5.7.9 Physical Protection and Safeguard Requirements for Spent Fuel Storage

Stored spent fuel is safeguarded against threats that fall into three broad categories: 1) theft of the fuel with the intent of extracting the contained plutonium and constructing a nuclear bomb, 2) theft with the intent of dispersing the material as a radioactive contaminant, and 3) sabotage to disperse radioactive material or otherwise interrupt operations. Spent fuel is not an attractive source of plutonium because the plutonium content is low (usually less than 1% by weight of the fuel), the fuel elements are very radioactive and require massive shielding of steel and lead or several feet of water at all times, and separation of the plutonium requires complex chemical processes carried out in remotely-operated shielded processing equipment. Theft of spent fuel for purposes of dispersing radioactive material or sabotage of spent fuel packaging or storage facilities would appear to be more attractive to an adversary and have more chance for success than theft for recovering plutonium.

Spent fuel has been stored in water basins at reactor sites and independent storage facilities (for example, Nuclear Fuel Services, GE-Morris, Hanford, and Savannah River Plants) for over 20 years without an incident arising from an attempt to steal the material or sabotage the facility. Because of the physical characteristics of the spent fuel, the probability of an attempt at theft or sabotage against spent fuel storage facilities is judged to be very low.

Spent fuel may be stored in any of the following ways (also see Sections 5.7.1 through 5.7.8).

- Water basin storage as bare fuel elements or packaged fuel elements.
- Dry storage in underground vaults as packaged fuel elements.
- Dry caisson storage underground as packaged fuel elements.
- Cask storage above ground as packaged fuel elements.

The storage facilities will be safeguarded in accordance with the requirements of 10 CFR 73[22] for protecting special nuclear material from theft and sabotage (see Section 3.9.2). An attempt by any unauthorized person or group to enter the facility would be detected immediately by the guards or intrusion alarm systems and the guard force would respond promptly. Safeguards contingency plans for licensed facilities will include NRC-approved arrangements for call-ins of local law enforcement support in the event of a serious threat. It is very likely that an adequate response force will be able to engage and contain the intruders in less time than would be required for the intruders to remove a fuel element from the storage location, transfer it to a shielded container, place it on a vehicle and leave the site. A single fuel element weighs 1/4 to 1/2 ton or more and a hoist or crane is required to move it. Disassembly to obtain individual fuel rods, which could be transferred by easily obtainable light equipment, would be a much more time-consuming operation.

Additional safeguards measures can be easily incorporated into the facility if judged to be necessary. For example, the controls of lifts, cranes and other equipment needed to move fuel elements from storage can be interlocked with the alarms; operational access can be limited by code control at the operations or safeguards control center or the facility; power supplies can be cut off by the security force from the security control center, which will be a hard-ended facility; and dead-bolt securing of packaged fuel in the caisson and cask storage arrangements can be used.

The safeguards measures normally required for licensed facilities also help deny access for sabotage of a fuel storage facility. In addition, the design and operational features for mitigating the consequences of design basis accidents have a similar effect in case a sabotage attempt is successful. One of these features is the requirement that fixed-site facilities be designed to withstand severe stresses such as earthquakes and tornadoes.

A detailed study of the safeguards risks associated with water basin storage of spent fuel has been reported.[23] The acts of sabotage studied were loss of water through sabotage of the basin equipment or rupture of the walls by explosives, ejection of radioactive material by explosion underwater, explosion adjacent to a fuel element suspended in the air, creating a criticality event by sabotage, and sabotage of fuel in a shipping cask. It was concluded that the stored irradiated fuel at the facility under consideration in that study is not amenable to a credible sabotage event that would result in the endangering of the public health and safety due to released radioactivity. The safeguard measures assumed for that case are typical of those required through the licensing process.

Although no specific sabotage risk analysis has been made for the dry storage concepts such as vaults, caissons, and casks, the physical protection measures required for vital facilities and Special Nuclear Material (SNM) access areas will be applicable (see Section 3.9.2). Consequently, it would be expected that intrusions would be detected and responded to promptly. The time required to remove a container or cask of fuel elements from the facility is believed to be in excess of the time necessary for supplementary guard and police forces to counter the threat. If a sabotage attempt were successful, a fuel cask may be penetrated by explosives and one or more fuel rods ruptured. The analysis of the environmental impacts of postulated accidents that result in fuel rod rupture, described in Sections 5.7.6.9, 5.7.7.9 and 5.7.8.9, indicated that the resulting releases of radioactive material would not be a significant public hazard. A more detailed safeguards risk analysis will be performed and an acceptable safeguards system specified before a dry storage facility is licensed.

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ACRONYMS LIST

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A-E	architect-engineer
AAPG	American Association of Petroleum Geologists
ACVSF	air-cooled vault storage facility
AEC	Atomic Energy Commission
AECL	Atomic Energy of Canada, Limited
AFR	away from reactor (spent fuel storage)
AGNS	Allied General Nuclear Services
ALARA	as low as reasonably achievable
AMAD	aerodynamic median activity diameter
AP	activation product
API	American Petroleum Institute
APS	atmospheric protection system
BFRSS	Barnwell Fuel Receiving and Storage Station
BIF	bitumen immobilization facility
BPPF	Barnwell Plutonium Product Facility
BTU	British thermal unit
BWR	boiling water reactor
CANDU	Canadian heavy water reactor
CDC	canister decontamination cell (cubicle)
CFR	Code of Federal Regulations
CIF	cement immobilization facility
CRWM	Committee on Radioactive Waste Management
CUP	cask unloading pool
CVCS	chemical and volume control system
CW	canistered waste
CWMS	Generic Environmental Impact Statement on Commercial Radioactive Waste Management, DOE-1559
CWTF	cask weld test facility
DCSF	dry caisson storage facility
DF	decontamination factor
DOE	Department of Energy
DOG	dissolver off-gas
DOP	dioctyphthalate
DOT	Department of Transportation
DTPA	diethylenetriamine pentaacetic acid
ECWS	essential cooling water system
EPC	engineering, procurement, and construction
ER	environmental report
ERDA	Energy Research and Development Administration
ESFS	engineered safety features systems
ESPS	essential spray pond system
FFTF	Fast Flux Test Facility
FP	fission product
FPF	fuel packaging facility
FRP	fuel reprocessing plant
FRPF	fuel residue packaging facility
FRSSF	fuel residue subsurface storage facility
FRVSF	fuel residue vault storage facility
FRW	fuel residue waste
FSA	fuel storage area
FSAR	Final Safety Analysis Report
FSB	fuel storage basin
FTF	fuel transfer facility
FTP	fuel transfer platform
GEIS	Generic Environmental Impact Statement
HCF	hulls compaction facility
HEPA	high-efficiency particulate air (filter)
HEU	highly enriched uranium
HLLW	high-level liquid waste
HLW	high-level waste
HM	heavy metal
HMA	hot maintenance area
HMF	hulls melting facility
HPF	hulls packaging facility
HTD	hulls transfer device
HTGR	high temperature gas-cooled reactor
HVAC	heating, ventilation, and air conditioning
IAEA	International Atomic Energy Agency
IBC	in-bed combustion
ICPP	Idaho Chemical Processing Plant
IFSF	independent fuel storage facility
IIPSF	independent interim plutonium oxide storage facility

ILLW	intermediate-level liquid waste
ILW	intermediate-level waste
INEL	Idaho National Engineering Laboratory
IPSF	interim plutonium oxide storage facility
ISFS	independent spent fuel storage
ISFSB	independent spent fuel storage basin
ISFSF	independent spent fuel storage facility
LAA	limited access area
LEU	low-enriched uranium
LHD	load-haul-dump
LLW	low-level waste
LN_2	liquid nitrogen
LSA	low specific activity
LWBR	light water breeder reactor
LWR	light water reactor
M&M	men and materials
MFBM	thousand board feet measure
MFRP	General Electric Company's Midwest Fuel Reprocessing Plant
MOX FFP	mixed oxide fuel fabrication plant
MP	mine production
MSRE	molten salt reactor
MTHM	metric ton heavy metal
NAA	normal access area
NAC	Nuclear Assurance Corporation
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NFS	Nuclear Fuel Services
NHLSW	non-high-level solid waste
NLI	National Lead Industries
NRC	Nuclear Regulatory Commission
NSSS	nuclear steam supply system
NWTS	National Waste Terminal Storage
ORIGEN	a computer program to calculate isotopic composition of irradiated nuclear fuel
ORNL	Oak Ridge National Laboratory
ONWI	Office of Nuclear Waste Isolation
OWI	Office of Waste Isolation
P-T	partioning and transmutation
PCWS	plant cooling water system
PFRF	packaged fuel receiving facility
PNL	Pacific Northwest Laboratory
POG	process off-gas
PSAR	preliminary safety analysis report
PWR	pressurized water reactor
R&D	research and development
RAA	restricted access area
RBOF	receiving basin for offsite fuel, Savannah River Plant
RCS	reactor coolant system
SCRA	storage cask receiving area
SCSF	surface cask storage facility
SF	spent fuel
SFPF	spent fuel packaging facility
SFRSS	spent fuel receiving and storage station
SFSF	spent fuel storage facility
SHLW	solidified high-level waste
SNM	special nuclear material, i.e., enriched uranium and plutonium
SRP	Savannah River Plant
SSC	sealed storage cask
SSCF	sealed storage cask facility
TBP	tributyl phosphate
TD	theoretical density
TN	Transnuclear Inc.
TRU	transuranic
TSA	transuranic storage area
TWCA	Teledyne Wahchang Albany
U-F	urea-formaldehyde
VE	ventilation exhaust
VOG	vessel off-gas
WBS	water basin storage
WBSF	water basin storage facility
WBSF-PF	water basin storage facility for packaged fuel
WCC	waste calcination cell (cubicle)
WCF	waste calcination facility
WIPP	Waste Isolation Pilot Plant
WTEB	waste tank equipment building
WVC	waste vitrification cell
WVF	waste vitrification facility

MEASUREMENT UNITS AND CONVERSIONS

MEASUREMENT UNITS AND CONVERSIONS

This report preferentially uses the metric system of measurements as defined by the International System of Units (SI). Common English units are often also included in parentheses. Prefixes used with the metric units are defined as follows:

Prefix	Abbreviation	Factor
giga	G	10^9
mega	M	10^6
kilo	k	10^3
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}

The following lists identify the symbols used in this report and the factors for converting between the SI and English units.

Symbols for metric units used in this report are:

Symbol	Name
°C[a]	degree Celsius
d[a]	day
g	gram
h (or hr)	hour
ha	hectare
kWh	Kilowatt-hour
J	joule
ℓ	liter
m	meter
min	minute
M	gram-mole/liter
MT	metric ton
MW-hr (or MWh)	megawatt-hour
s (or sec)	second
W	watt

a. Units which are not strictly SI but which are widely used.

Symbols for other units used in this report are:

Symbol	Name
atm	atmospheric pressure
BTU	British thermal unit
Ci	curie
°F	degree Fahrenheit
ft	feet
gal	gallon
in.	inch
lb	pound
MFBM	thousand board feet measure
psi	pounds/square inch
R	roentgen
rem	roentgen equivalent man
yd	yard
yr	year

To convert metric to English, multiply by:

Metric	English	Factor
°C	°F	(°C x 9/5) + 32
cm	inch	0.3937
ha	acre	2.47
kg	lb	2.205
km	mile	0.6214
ℓ	gal	0.2642
m	ft	3.281
m^2	ft^2	10.76
m^3	MFBM	0.424
m^3	ft^3	35.31
m^3	gal	264.2
m^3	yd^3	1.308
MT	ton	0.9070
W	BTU/hr	3.413
W-s/kg-°C	BTU/lb-°F	2.39×10^{-4}
W/m-°C	BTU/hr-ft-°F	0.576

To convert English to metric, multiply by:

English	Metric	Factor
acre	ha	0.405
BTU	W-hr	0.2931
BTU/lb-°F	W-s/kg-°C	4187
BTU/hr-ft-°F	W/m-°C	1.735
°F	°C	(°F-32) x 5/9
ft	m	0.3048
ft^2	m^2	0.0929
ft^3	m^3	0.0283
gal	ℓ	3.785
gal	m^3	3.785×10^{-3}
inches	cm	2.540
lb	kg	0.4536
mile	km	1.609
MFBM	m^3	2.360
ton	MT	1.103
yd^3	m^3	0.7646